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Some Recent Developments in Light Control

By R. W. Stevens, B.Sc., F.S.I.A. (*Fellow*)

Summary

After a brief consideration of the fundamental principles involved, a number of recent developments in the techniques of light control are reviewed. Particular reference is made to the application of injection moulding techniques to the manufacture of prismatic assemblies and the use of new aluminium alloys and finishing methods in the construction of specular reflectors. A method of distributed light control is also described, whereby a number of spaced locations may be lit by a single remote source.

(1) Introduction

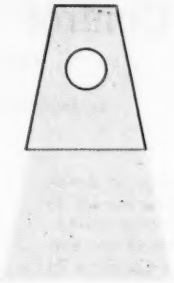
There are three major fields of illuminating engineering. The first is concerned with the provision of light, the second covers the control of light and the third covers all applications of light. The control system is thus a link between the initial production of light and its final use. Its physical form is, therefore, very closely governed by both aspects, by the nature of the source itself and the application. The purpose of this paper is to review some recent developments in methods of light control and to examine the mutual interaction between these and the development of light sources and the techniques of illuminating engineering. It does not form a comprehensive survey and it is hoped that contributors to the discussion will help to make it more complete by describing other examples of developments in this field.

(1.1) The fundamental basis of light control

The basic laws of light control, the laws of reflection, refraction, diffusion, diffraction and polarization, have long been well understood, including those factors having an effect on the amount of light emitted, such as transmission losses, reflection losses, losses at an air/glass interface, etc. Developments, therefore, are in the main refinements of techniques or they are based on the application of newly developed materials. There is one aspect, however, that may be worth enlarging on and that is the fundamental basis of light control.

It is possible to approach this in two ways; firstly the source is considered to produce a given amount of light and the purpose of a light control system is to redirect this flux in certain desired directions; secondly the light source is regarded primarily as an area of given brightness and the purpose of the light control system is to modify the distribution by altering the area of brightness. Thus the intensity of light from a source in any direction is considered to be due to a projected area of given brightness or

$$I_\theta = B_\theta \times A_\theta \quad \ldots\ldots\ldots\



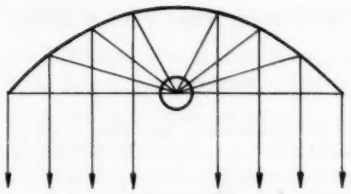


Fig. 1 (*left*).
A concentrating fitting?

Fig. 2 (*right*). *True functional form of a concentrating fitting.*

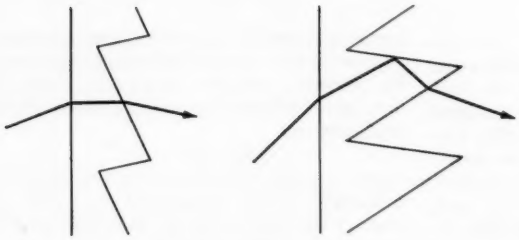


Fig. 3. *The two basic forms of light control prisms.*

herent losses, so that the brightness of the image is not as high as the source itself, in fact providing an image of equal size will not quite double the luminous intensity. It follows that if we wish to achieve a given intensity the size of the light control system must be greater than a certain amount and a guide to this is provided by equation 1. In this equation, therefore, we can regard B as a fixed amount or certainly not greater than the brightness of the source itself and to achieve the required intensity A must be increased. This largely determines the size of the lantern itself, and any attempt to make it smaller (an attempt often made in the case of fluorescent lanterns) is bound to result in a fall off in performance. This may well be warranted on aesthetic grounds but is not expected by the layman.

(2) Control by Refraction

The bending of light as it passes through the interface between air and a transparent substance has always been used extensively as a means of control. This has generally been achieved by a series of prismatic flutes on a supporting base. The two basic forms, refracting prisms and reflecting prisms, are shown in cross section in Fig. 3.

(2.1) Injection moulded refractors

Recent developments have come in the main from exploring the possibility of injection moulding of prismatic assemblies.[2] This in turn is due to the introduction of suitable clear plastic materials such as polystyrene, butyrate and acrylic resins in injection moulding forms.

Advances in the design of lighting equipment are due to many factors; new requirements in lighting applications, a new light source, new methods of production, new materials, and the most difficult to arrive at, of course, a simple good idea. That is why a new material probably involving new production methods, is eagerly welcomed by the designer. When its properties are advantageous a careful assessment of them can hardly fail to suggest novel lines of development. Five years ago acrylic resin in an injection moulding form was such a material and compared with glass or even acrylic sheet, it had many interesting possibilities.

All materials have their disadvantages; injection moulded acrylics are no exception. The principal one, as far as street lighting applications are concerned, is a low softening point compared with glass or metals. In several ways its thermal properties are quite different even from those of glass. Its thermal capacity is very small and its thermal conductivity extremely low. The low thermal capacity means that only a small amount of heat need be absorbed to raise the temperature of the component considerably. The low thermal conductivity means that this heat will not be dissipated through the body of the component; there will be considerable variations in temperature and there is a danger of 'hot spots', with considerable local demoulding.

(2.2) Thermal tests

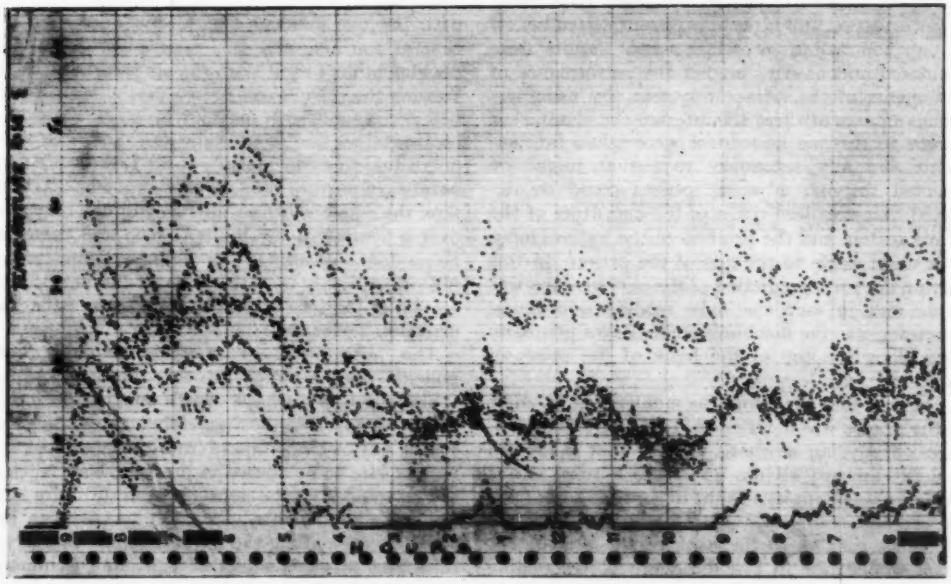
It is perhaps worth mentioning that one result of these particular properties is that the question of the method of testing must be approached with some care. Under still air conditions in a typical draught-free testing enclosure this will be especially true and tests made in this way are likely to result in very conservative ratings of components. Conversely, only a small amount of heat need be removed from a component to cause an appreciable temperature drop and the slightest air movement will be sufficient to do this. An example of the difference this makes is shown by the result of a series of tests carried out on an open type Group B street lighting lantern with an injection moulded acrylic refractor. Fig. 4 shows a typical trace of temperature measured by attached thermocouples. The violent temperature fluctuations show how sensitive these measurements are to the slightest amount of cooling, for this particular trace was taken during an ostensibly calm evening. The interesting point is that even the greatest upward rise is to a temperature nearly 10°C. below that measured in a draught-free enclosure. With a totally enclosed lantern, the difference is not so great but it is still appreciable and in practice considerably simplifies the problem of using acrylic components close to high rating lamps, since any simple way of cooling the component, by allowing even a restricted passage of air, or providing internal shielding, is effective in reducing temperature to safe limits.

(2.3) Aspects of design

Unlike a reflector system, where the performance is decided entirely by the shape, a refractor system allows the designer a certain amount of freedom in deciding the general configuration. Injection moulding allows this freedom to be fully exploited and even more, it allows detail of some considerable complexity to be incorporated with close tolerances of dimensions. The material itself has good mechanical properties and, in addition, injection moulding allows local thickening and stiffening webs to be readily incorporated. In street lighting lanterns the light control system, the transparent enclosure and the structural form have usually been provided by assembling components that separately fulfil these functions. Thus a typical lantern housing a 140-watt sodium lamp may have a cast aluminium canopy, a bowl formed from clear acrylic sheet and prismatic plates cemented to the bowl. It seemed possible with the advent of injection moulded acrylics that a single unit could be evolved that fulfilled all three functions in an integral structure.

The concepts outlined above were explored in detail with the aim of producing a street lighting

Fig. 4. Plot of temperatures measured by thermocouples attached to the acrylic plastic refractor of an open type street lighting lantern during a prolonged outdoor test.



lantern for Group A roads using the 140-watt sodium lamp. It has already been pointed out that injection moulding allows some freedom in determining the actual shape of the lantern, a freedom that one is tempted to exploit, but there is at least one major difficulty. The main part of the lantern as finally developed consisted of two parts (one of which is shown in Fig. 5), bonded together to form an enclosure that could be hermetically sealed. The tools for moulding these components cost over £2,000 each and any modifications to them would have been proportionately expensive. It was necessary, therefore, that tools should be commissioned with considerable confidence that little, if any, modifications would be required. It was possible to check the mechanical and thermal features of the mouldings fairly readily by construction of models, but full size models of refractor systems for photometric tests are very difficult to make to the necessary degree of accuracy, especially if curved surfaces are employed. The difficulty was overcome in this instance by checking the performance in two stages. A full size model of the lantern was made but with the reflector portion blanked off, and the distribution of this arrangement with a lamp in its correct position was investigated. To this distribution was added that of the refractor determined separately in the following way:

Ten times full size models were made of sections of the prism in sets of three. These were set up on a specially constructed form of goniometer as shown in Fig. 6. Careful measurements were then made of the direction and intensity of transmitted beams of light, including secondary rays. Results were tabulated and used to predict the performance of increments of the refractor system. By using the prisms in sets of three the interference of adjacent prisms to the one under test were taken into account and any secondary rays that might be directed through adjacent prisms could be detected. Account was taken of the curvature of the whole system and the position of the sodium lamp at a slight angle to the line of the prisms. In this way an accurate prediction of the performance was made and in fact the only modification found necessary was the machining of an extra prismatic flute along the top of the bank of the prism in each side.

The fact that the lamp was mounted at an angle to the prisms was mentioned. This had two advantages; firstly, an aesthetic one, in that it allowed a slight upward alignment of the lantern whilst the lamp was kept at a slight downward angle from the cap and, secondly, a photometric one. With the arc tubes parallel to the bank of the prisms, the latter would flash in two directions corresponding

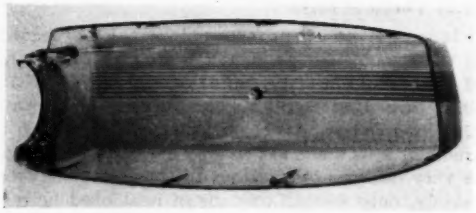


Fig. 5. Half section of a street lighting lantern for the 140-watt sodium lamp injection moulded in acrylic plastic.

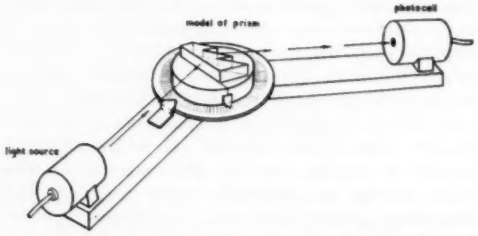


Fig. 6. Experimental arrangement used to determine the performance of 10 times full size sectional models of prisms.

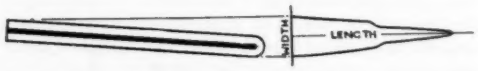


Fig. 7. Effective width of the 140-watt sodium lamp when at an angle of 3° to the direction of a prism bank.

with the two incident angles, one from each section of the arc, and this may result in double-peaking in the beam. With the arc tube at an angle, viewing the prism bank from a particular direction will correspond with incident rays coming from a horizontal section of the tube and this section will only equal the whole length of the tube over a comparatively narrow band, as shown in Fig. 7. Therefore, the whole width of the reflector can only flash over a comparatively limited angle and there can be no double peaking. The luminous intensity will fall off smoothly on either side of the peak as the section of the tube corresponding to any particular direction decreases.

The possibilities of injection moulded components were explored in other lanterns and one other point is perhaps worth mentioning. In a simple Group B lantern an elaborate focusing system is out of place; apart from the high cost it is almost sure to be abused in practice. Nevertheless, the tolerances on the light-centre length of a lamp are quite appreciable and ought to be taken into account. By making the refractor consist largely of reflecting prisms instead of the more commonly

used refracting prisms, the system becomes to a degree self-compensating and changes in light centre lengths have comparatively little effect on performances as can be seen from the typical distribution shown in Fig. 8. The use of an injection moulded component allows the comparatively fine reflecting prisms to be used extensively, and the effect is as follows:

Light emitted in the direction of the main beams of the lanterns comes in part from the bare source itself, which is arranged to be cut off by the refractor rim above the direction of the peak and in part from the refractor. In Fig. 9 the bank of prisms on the wall of the lantern has been replaced diagrammatically by a single prism. It will be seen that raising the position of the source lifts the direction of the rays from the prisms and at the same time the cut-off to the source itself is depressed. The two effects tend to cancel. With refraction prisms, on the other hand, the movement of the two components of the beam would be in the same direction and the distribution would be sensitive to changes of light centre length.

(3) Control by Diffusion

Diffusion is another transmission process, but in its passage through the material the light is scattered by a solid suspension of minute particles. The mechanism was described in detail in connection with opal acrylic plastics in a paper presented to the C.I.E. in 1951.[3] Developments since that date have again largely followed the introduction of new materials, many again in a form suitable for the production of components by injection moulding. Unlike the introduction of the clear transparent moulding powders, the new materials have not yet resulted in any marked changes in the form of lighting equipment. The introduction of extruded forms of these materials has, on the other hand, resulted in a characteristic form of diffuser fitting for use with fluorescent tubes. (Fig. 10.) This general form of diffuser was not unknown, of course, when only sheet acrylic materials were available, but it is worth nothing that when extrusions are used it is not possible to produce the closed end diffusers that can be readily formed from the sheet. This closed end form of diffuser is still required and in particular the 'slab' or 'wafer' type of fitting shown in Fig. 11 is popular. This form of diffuser is re-entrant at the ends as well as the sides and is produced on a collapsible tool. The forming process involves considerable stretching of the material and in normal grades of acrylic sheet, the resulting thinning can result in undue transparency. This has been overcome by the introduction of a special grade of opal incorporating a

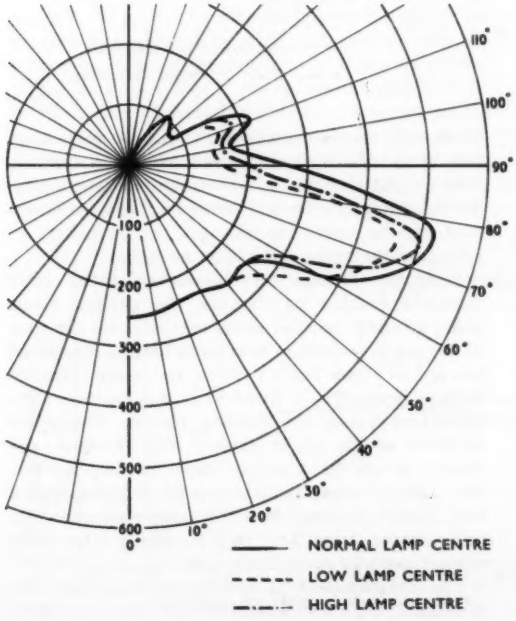


Fig. 8 (*left*). *Self-compensating effect of reflecting prisms on performance of a street lighting lantern as the light centre length varies between the accepted tolerances for the lamp dimensions.*

Fig. 9 (*below*). *A diagrammatic representation of the self-compensating effect of reflecting prisms.*

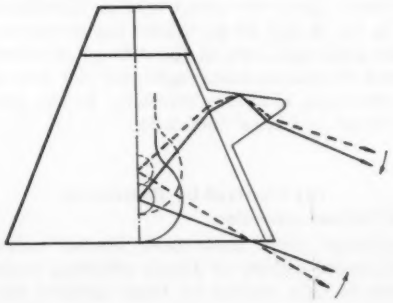
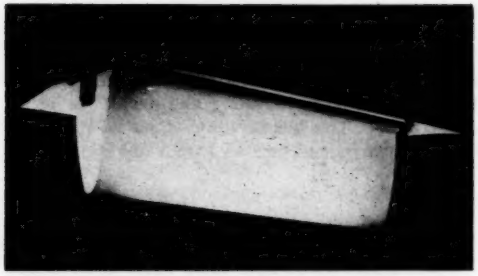
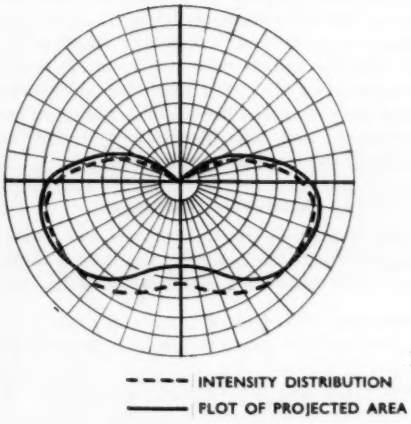


Fig. 10 (*above*). *A fitting incorporating an extruded acrylic diffuser. Fig.* 11 (*above right*). *A fitting incorporating a diffuser that is re-entrant on all four sides: special grades of acrylic sheet material have been developed that maintain a good degree of obscuration, especially at the corners, despite the extreme stretching that occurs.*
Fig 12 (*below*). *A street lighting lantern in which the distribution is controlled by shaping the diffusing bowl. Fig.* 13 (*right*). *The correlation between the projected area of the bowl of the lantern in Fig.* 12 *and the light distribution.*





new form of pigmentation which causes increasing opacity as the material is stretched and thus compensates to a considerable degree for the transparency found in normal materials.

One further development may be mentioned, since it illustrates the application of equation 1 to matters of light control and shows how a diffuser may be used to achieve a desired light distribution. This is the street lighting lantern shown in Fig. 12. In Fig. 13 the dotted line shows the plot of the projected area of the diffuser in directions around the major axis, whilst the full line shows the measured luminous intensity. It will be seen that there is a close correlation.

(4) Control by Reflection

(4.1) Diffuse reflection

Although there have been gradual improvements in the quality of diffuse reflecting materials the art of light control by these surfaces has not made any marked advances. Certainly they have had little influence on the appearance of lighting fittings and changes in the design of interior reflector fittings for incandescent or discharge lamps that can be traced to changes in the nature of reflecting materials have been marginal.

Reflector fittings for fluorescent tubes have shown a number of changes, the general trend being towards smaller cross sections. In the case of the popular form of two-lamp fitting, this trend has led to closer lamp spacing and more compact fittings generally, a trend that has been accompanied by a drop in efficiency but one that is not as great as one might expect. Fig. 14 shows the change in the light output ratio as lamp centres are varied in a two-lamp closed top reflector with a 9 in. mouth opening. It will be seen that changing lamp centres from 3 in. to 2 in. changes the light output ratio by only 2 per cent.

The development of stoving enamels that will withstand high temperatures may have an influ-

ence on the design of fittings. Based on epoxy resins, they have as yet had limited application. Another useful property of these finishes is the very good bond achieved with clean metal surfaces or even an anodized surface, eliminating the need for the usual priming treatment.

(4.2) Specular reflectors

In the field of specular reflection there has been considerable progress. To a large degree these are results of advances in the techniques of using aluminium and its alloys. Possibly the most important advance has been the development of methods of electrolytically and chemically polishing aluminium[4,5,6]. This, coupled with the availability of new aluminium alloys, has allowed a reasonable degree of specular reflectivity to be achieved without incurring the high cost of super-purity aluminium and at the same time avoiding its softness.

A distinction should be made between brightening processes and polishing processes.[6] The former were developed in the 1930's and are typified by the well-known Brytal and Alzac treatments, the main effect being an increase in reflectivity with little or no smoothing action. Reflectors need to be well finished by a mechanical polishing process before treatment. An electro or chemical polishing process, on the other hand, has a marked smoothing action. Probably the most popular is the Erthwerk process, a simple immersion for some 15 to 30 seconds in a solution of nitric acid and ammonium bifluoride, with small amounts of other additives. Other processes use a phosphoric-sulphuric acid mixture. An appreciable amount of metal is removed by these processes and must be allowed for in selecting material thickness for fabrication. These processes can entirely replace hand polishing or can be used to supplement an initial hand treatment. They are very effective in removing scour marks, scratches and other surface markings and result in a very bright clean surface. They are particularly useful when the surface configuration is somewhat intricate, where they can show an appreciable economic advantage over the normal hand finishing processes. This does not necessarily hold for the simple smooth contour since operating costs are fairly high.

These processes have probably been developed mainly for the motor-car industry with the aim of replacing chromium plated trim with anodized aluminium. In this case clarity of image is the aim, not necessarily a high degree of reflectivity. For lighting purposes the aim is reversed. Good specular reflectivity is required, not necessarily associated with perfect image clarity. In practice this allows a greater freedom of choice in the selection of suitable alloys. The most useful are those with a small magnesium content, since the mechanical properties of these are much superior to super-purity aluminium. An alloy with the magnesium content of 1·5 per cent, for an example, treated with a modified Erthwerk process can have a specular reflectivity of over 85 per cent.

(4.3) Applications in street lighting

The street lighting lantern shown in Fig. 15 is an example of the influence such developments have had on the design of lighting equipment. The reflector, a single pressing in an aluminium magnesium alloy, is an involved shape with two main side control surfaces and faceted upper surfaces. Hand polishing of these would be prohibitively expensive but the use of chemical polishing makes it an economic proposition. It is perhaps worth while examining the development of the light control system in some detail.

The introduction of the colour corrected mer-

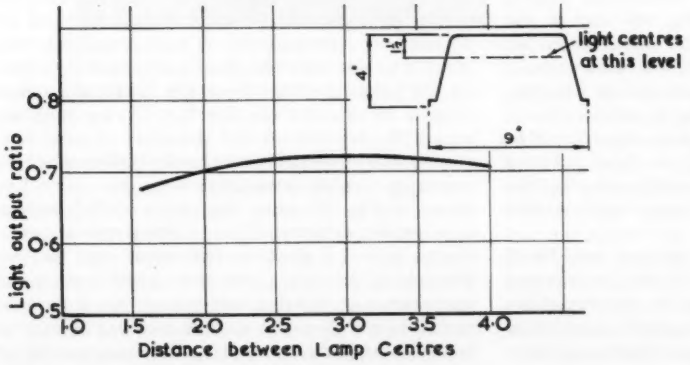
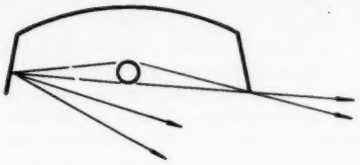
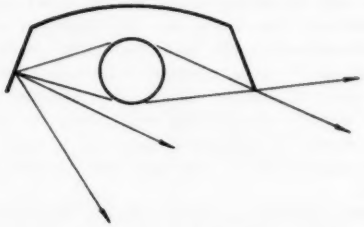


Fig. 14. Variation in the light output of a trough reflector as the light centre distance is varied.

Fig. 15 (*left*). *A street lighting lantern employing a chemically polished and anodized aluminium-magnesium alloy reflector.*

Fig. 16 (*below*). *Effect of source size on angular rate of cut-off in a reflector lantern.*





cury lamp of 250 and 400 watt ratings in this country in 1955 provided a new light source of reasonably good colour for street lighting. The high output from a comparatively small source made it an obvious alternative to the fluorescent tube for urban street lighting. On the other hand, the source size was several times larger than the plain mercury lamp, so that to achieve the same degree of control efficiency the lantern had to be somewhat larger than one designed for the latter lamp. Moreover, it seemed likely that there was a danger of glare from a lantern with inadequate control and that glare would be particularly difficult to avoid with a refractor system; even with a reflector lantern it would not be easy to achieve good cut-off characteristics, unless the dimensions of the reflector system were related to the size of the source. With a plain mercury lamp the reflector system could be arranged to form a main beam passing under the lamp as shown in Fig. 16a, but if the same attempt is made with the colour corrected lamp, this results in either too low a beam angle or poor cut-off characteristics, as shown in Fig. 16b. Increasing the size of the lantern allows one to achieve two things. Firstly the main beam could be formed, partially at any rate, by light reflected round the end of the lamp, secondly, cut-off of the source itself could be achieved over a much smaller angle.

The contours of the two side sections were based on paraboloids with the focus at the lamp centre and this in turn was placed well to one side of the geometric centre, of the lantern system. Light from the source emitted in an upward direction is controlled by the faceted upper section of the reflector and is redirected to give a smooth decrease in intensity from the peak to the downward vertical. At the same time intensities across the road are maintained, while those behind the lantern are reduced to avoid annoyance to occupants of adjacent properties. The design of such a reflector system requires a certain amount of trial and error. A change in the angle of a face by one degree will change the direction of a reflected ray by 2°. In addition, secondary reflections can be troublesome, particularly with a large source. Investigations were therefore carried out with prototype reflectors and a useful technique employed was to photograph the unit from a series of known directions corresponding to portions of the isocandle diagram that it was necessary to examine. In this way intensities could be related to the degree of flashing of various sections of the reflector and any part of the system requiring modification could be determined. Alternatively, it was sometimes convenient to eliminate the photograph itself by viewing the prototype directly on the screen of a reflex camera. In this way the direction of view could be accurately determined and the effect on modifications quickly assessed. A series of photographs of a prototype under investigation in this way are shown in Fig. 17. Since the shape of this lantern was largely determined by photometric requirements, it had a characteristic form, and was an example of the direct influence of function on the appearance of lighting equipment. In an actual installation it allowed a marked decrease in glare to be achieved without requiring the close spacing of

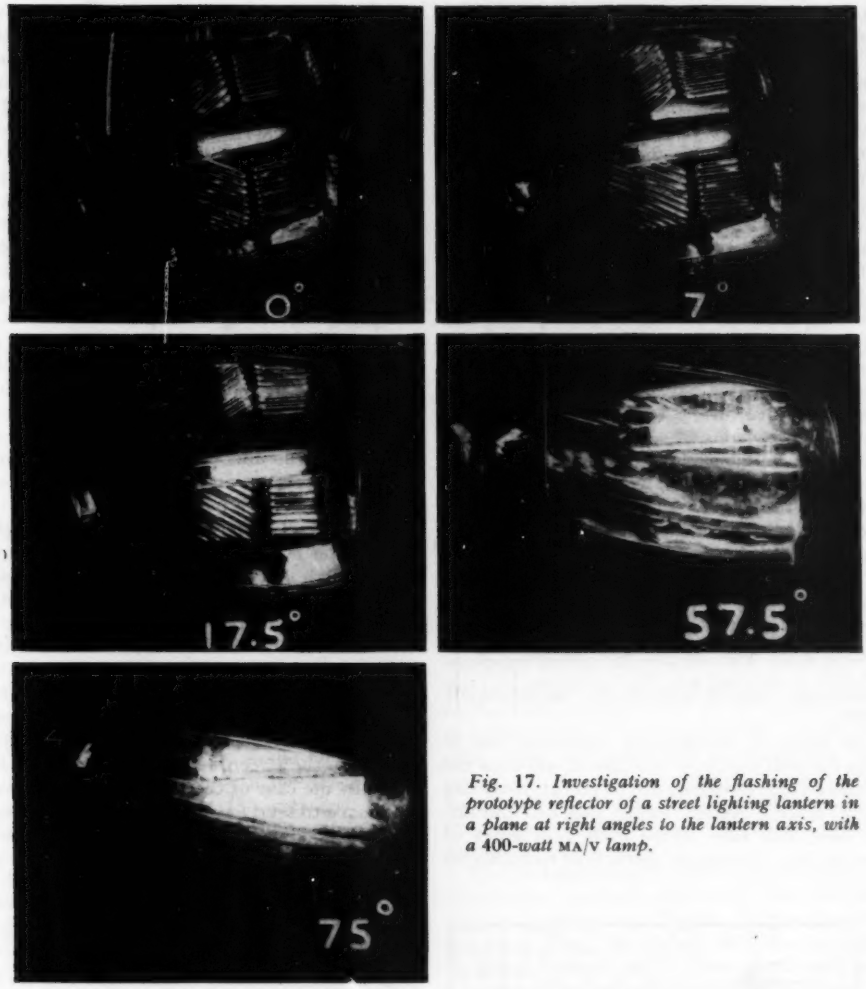


Fig. 17. *Investigation of the flashing of the prototype reflector of a street lighting lantern in a plane at right angles to the lantern axis, with a* 400-*watt* MA/V *lamp.*

units normally expected with a true cut-off installation.

(4.4) Specular reflectors with fluorescent tubes

In this country, specular reflectors have not been used to any great extent with fluorescent tubes, a fact probably due to the relatively high cost of large reflectors of anodized super-purity aluminium. They have, of course, been successfully used in street lighting lanterns, although the bulk of the lantern necessary to house an efficient light control system has provoked criticism on aesthetic grounds. A number of reflector units giving directional effect have been marketed for commercial applications but often efficiency has been sacrificed on the grounds of economy by the use of commercial grades of aluminium. It has been shown recently how the use of polished reflectors and louvres allows the brightness of the fittings in directions approaching horizontal to be controlled[7,8], and there may well be an increased use of such fittings as the need for lower brightness for satisfactory visual comfort is appreciated.

Where a directional effect has been required the

reflector contour has usually been based on the parabola. An alternative contour has been proposed which, with a tubular fluorescent tube, results in a peak intensity along the axis with a sudden cut-off on one side only.[9] A typical contour and the resulting distribution of intensity are shown in Fig. 18. When a fluorescent tube is used with a reflector of parabolic contour the size of the source is usually large enough to mask any slight inaccuracies in forming the reflector and it is not difficult to achieve the necessary accuracy of contour by normal rolling methods. The curve in Fig. 18 on the other hand is mathematically related to the cross-sectional dimensions of the tube and the sharpness of the cut-off depends entirely on the accuracy with which the contour is maintained. The properties of this particular reflector contour have been used in various applications such as airfield runway lighting and also for low level street lighting[10,11]. A number of units were used in a trial of low level lighting at Longniddry early in 1959[12]. In this case the cut-off line was directed at the curb of the opposite side of the carriageway as shown in Fig. 19. Since intensities above this line were of a low order, it was possible to avoid completely the 'flashing' effect in drivers' eyes as their vehicles passed each unit, an effect which is normally the worst feature of such lighting systems.

(4.5) Specular control systems for incandescent lamps

In the realm of floodlighting, where the use of reflector systems is almost traditional, perhaps the most interesting developments of recent years has been the Infranor system. Again, polished aluminium is used, this time in the form of a series of narrow bands of thin gauge sheets held to parabolic or elliptical contours in separate formers. A set of these reflectors is held in controlled relationship with the light source—a front silvered incandescent lamp—and each gives a rectangular distribution of light, the actual angular distribution being determined by the geometric relationship between the source and the reflector element. This relationship is, in fact, adjustable, and the beams from each segment may be made to coincide or lie adjacent in space. The rectangular beam from the floodlight can thus be made to relate to the size and orientation of a building or a series of buildings. Two advantages arise from the front silvering of the lamp. Firstly, no direct light escapes from the floodlight, all emitted light coming from the reflector system within the designed limits. Not only is this very convenient when precise control of light distribution is required, as for example in a Sound and Light spectacle, but also is of considerable advantage where the unit is fixed close to a public right of way, annoyance and disturbing glare can usually easily be avoided by careful orientation of the units. Secondly a high proportion of the light output of the lamp is emitted towards the reflector and a high overall efficiency results. This high efficiency, coupled with the ability to match the distribution with the requirements of a particular situation are the main attributes of the system.

The luminous efficiency of a precise light control system is often notoriously low, thus the efficiency of a searchlight projector or of a cinema projector measured in terms of lumens in the beam or received on the screen, respectively, is only a few per cent. In the case of the searchlight, it is, of course, necessary to send only a relatively few lumens into a small solid angle to achieve high intensity. A thousand lumens in a beam subtending only one de-

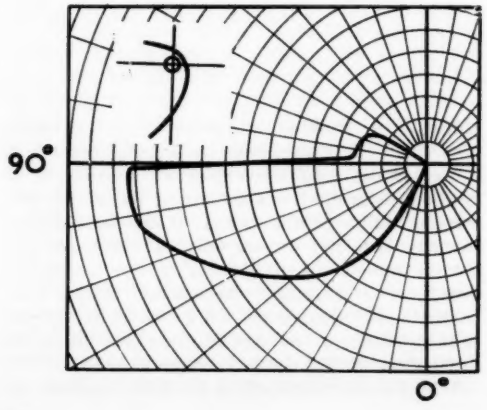
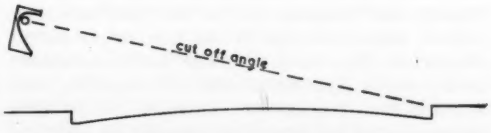
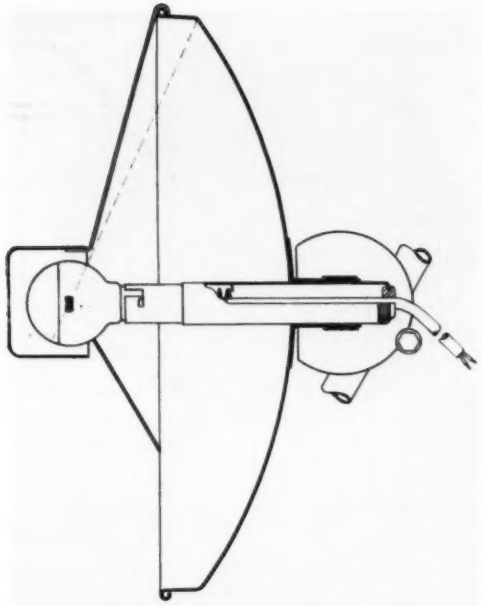


Fig. 18 (*left*). *A reflector contour to give controlled cut-off with a fluorescent tube and the resulting distribution of intensity.*

Fig. 19 (*below*). *Orientation of the cut-off type reflector for low level street lighting.*





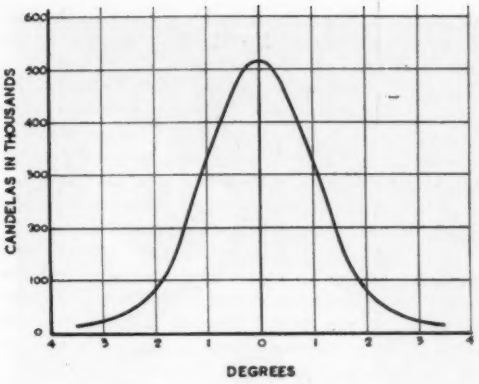


Fig. 20 (*left*). *Sectional detail of a very narrow beam projector employing a* 24 *volt* 150-*watt coiled coil lamp.*

Fig. 21 (*above*). *Distribution curve for the projector shown in Fig.* 20.

gree will give an intensity of some 3½ million candelas. In theory, therefore, a unit with a source of low rating should be capable of providing a very high intensity, but the source size must be small to achieve the narrow beam spread required. A compact source discharge lamp would be suitable, but a convenient alternative is a low voltage incandescent lamp. A 24 volt 150-watt coiled coil lamp with a source size of 4 mm diameter, 8 mm long, was used for the base of the design of an efficient narrow beam projector. The advantages of front silvering have already been described and the technique was used with this low voltage lamp. The filament was placed just off centre in a 5 mm diameter spherical bulb so that the real image formed by the silvering lay adjacent to the actual source. The extent of the silvering was related to the angle subtended by the boundary of the parabolic reflector, as shown in Fig. 20. In this way some 700 lumens were emitted in a beam submitting a total angle of less than 3° and resulting in a peak intensity of about 500,000 candelas. (Fig. 21.)

Such developments have given a new freedom in the positioning of local lighting units. Previously the provision of a high illumination level over a small area has generally required a fitting mounted close to the area, a requirement that can be rather inconvenient, whether it is a question of lighting a display feature or the local lighting of a machine tool. A 6 in. diameter version of the unit described equipped with a 12 volt 50-watt lamp provides a level of some 200 lm/ft² at a distance of 15 ft. Other applications are as varied as the lighting of dials in a plant room or the supplementary lighting of an office desk. The larger unit allows an even greater range, and apart from interior applications, has been used for floodlighting architectural features from a long distance—up to nearly a quarter of a mile in one instance.

The problem of the cinematograph projector, at least in the amateur's 8 mm size, has been tackled by incorporating an efficient elliptical reflector in the lamp itself, dispensing with the conventional condenser system. A 150-watt lamp in one particular projector provided as high a screen illumination as the usual 750-watt lamp with a standard condenser system. There are two principal requirements of the source-condenser system in a projector. Firstly, the film gate must be evenly lighted and secondly, as much light as possible must be directed through the gate. This is usually achieved by projecting the image of a rectangular source on the gate, the image being slightly blurred to avoid a clear image of the filament structure. This is achieved with an internal reflector by making this of elliptical contour with the source at one focus and the gate at the other. The reflector is nickel-plated and flashed with silver, giving a reflection of about

95 per cent. Since the reflector is close to the filament a high proportion of the light emitted by the latter is collected and redirected on to the gate. The light gathering properties of this reflector results in a much higher efficiency than with the normal system, but to maintain it, it is necessary to achieve a high degree of accuracy in the alignment of the filament and the reflector and also to maintain an accurate alignment of the two with the position of the base. The necessary degree of accuracy is achieved by mounting the reflector and filament directly to a glass base of the type used in radio valve construction and this assembly is independent of the bulb. This, of course, is quite different from the usual form of lamp construction where the filament assembly is mounted in relation to the bulb itself and the latter adjusted in position in the lamp cap, the arrangement normally used in prefocused incandescent lamps.

(4.6) Distributed light control

The development of an efficient narrow beam projector system suggested the possibility of using a remote light source with the means of extracting light at a number of positions along the beam. Such an arrangement, it was thought, might be useful, for example, for the lighting of a series of adjacent locations of a dangerous nature. In this case one would mount the projector system in a remote and safe area, projecting the beam of light above the locations to be lit and then arranging at each point an interceptor that would redirect part of the light in the beam, thus becoming in effect a local source of light and at the same time allowing the greater proportion of the beam to pass through to further interceptors. An experiment was carried out using the 14-inch diameter projector described above, equipped with the 24 volt 150-watt front silvered lamp. A series of flat rings of opal acrylic sheet of decreasing internal diameter were arranged along a path of about 50 ft. in length, the largest, of course, being nearest the projector. It was found that such a system had some interesting properties. It was, for example, inherently self-defining, the rings automatically limiting the beam as the distance from the projector increased. It was also found to be an easy matter to distribute the light in the beam in a uniform manner over the series of interceptor diffusers, by suitably adjusting the inner diameter of the rings.

The properties of a parabolic mirror were considered in detail by Benford in the period from 1923 to 1926[13] and in one paper[14] he analyses the variation in illumination on a plane intercepting the beam at various distances from the projector. However, as Benford remarks, the distribution is

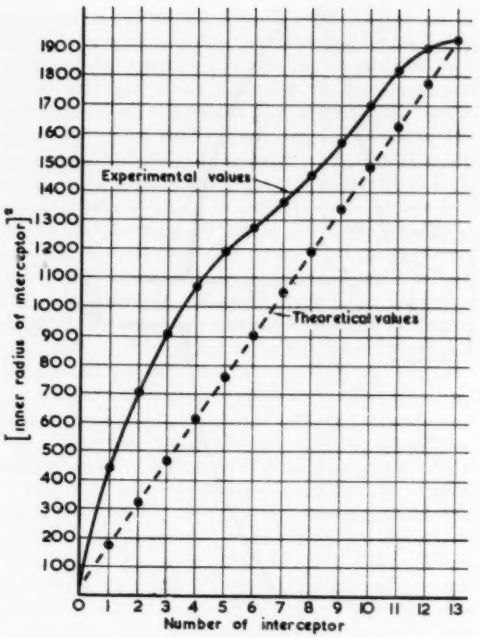


Fig. 22. Theoretical and experimental distribution of interceptor internal diameters to give equal amounts of intercepted light flux.

not really amenable to calculation, since the flashing of the mirror, especially when viewed from a short distance, depends so much on the actual shape of the source and the figuration of the mirror. An elementary analysis indicates that for an even division of the light flux the difference in area between two adjacent rings should be constant. Thus in Fig. 22, which is a plot of the square of the hole diameter against the number of the ring, the plot of the diameters is a straight line if the difference in area is to be constant. If the first few rings are very close to the projector there will probably be so much scattered light generally that the interceptors will only make a partial contribution to the lighting level, and if this is to be constant, the difference between the inner diameters must be reduced. On the other hand, at distances remote from the projector, the inverse square law will begin to apply and to compensate for the fall in illumination level the difference between adjacent inner diameters must be increased. The plot of ring diameters for an even distribution of light is, therefore, curved, as shown in the diagram. This curve was in fact determined experimentally and it

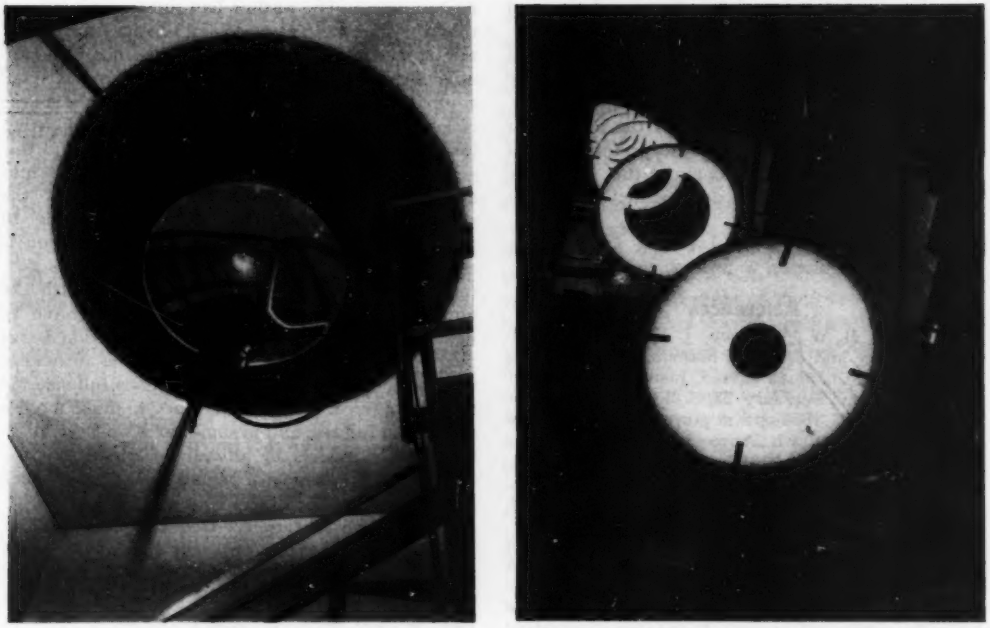


Fig. 23. A distributed light control system in a stair-well. (a) The 3 kW projector, (b) a view of the array of ring diffusers

will be seen that a difference in area between rings is large for the first few rings, becomes roughly constant over the middle range and reduces for the rings near to the projector.

By measuring the area and the brightness of the halo of light on each ring, confirmation was obtained of the low losses that it was suspected would be inherent in such a system, for it will be seen that light that is not intercepted by a diffuser is not lost but passes on to the next in the series and if the rings are of opal acrylic sheet with primary transmission and reflection factors of 52 and 42 per cent respectively, the loss is only 6 per cent and this figure applies to the complete system. The overall efficiency is determined largely by that of the projector.

An opportunity to try out a full scale version of this was found in the main staircase of a large office tower block. This rose through some 13 floors to a height of about 180 ft. The main staircase had a square centre well that was about 4 ft. across. The largest parabolic mirror that could be used was 44 in. in diameter and a standard silvered glass searchlight mirror having a focal length of about 20 in. was adopted. For a source a special 110 volt 3-kW filament lamp was developed suitable for cap down operation, the lower half of the bulb being silvered to give maximum utilization of the flux emitted by the filament.

It was anticipated that it would be necessary to modify the calculated dimensions of the rings to achieve a truly uniform distribution of light among the interceptors, particularly in the case of the rings close to the projector and those farthest away. An initial trial was therefore made with the white painted metal rings of the dimensions given by the straight line in the diagram and it was found that a uniform distribution was achieved down to the fourth floor. After that the amount of light at each floor fell off continuously. It was eventually determined that for a uniform distribution the internal radii of the rings should follow the dotted line on Fig. 22. Photographs of this installation are shown in Fig. 23.

(5) Conclusion

An attempt has been made not only to describe some recent exercises in light control, but also to show how these have been influenced by developments in the field of light sources and materials, how they have influenced some techniques of lighting application and how the consideration of

these matters influence the general form and appearance of illuminating engineering equipment.

The author is indebted to many colleagues and friends in industry whose help has made it possible to successfully complete many of the projects described in this paper; in particular the help of Mr R. H. Simons in invesigating the performance of various systems and overcoming the inevitable snags that arose in the development work, is gratefully acknowledged.

The Directors of Atlas Lighting Limited are thanked for permission to publish this paper.

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Discussion

MR H. M. FERGUSON: May I congratulate the author on a most interesting paper. There are so many points of interest that I am having to confine my remarks to the first part of the paper, which deals with some of the points arising from the design of street lighting lanterns. Now the author has mentioned the two principal concepts of light control, the flux concept and what I prefer to call the flash concept. The author has rightly pointed out that the flux method of design has its limitations: nevertheless it is not to be ignored since it is capable of giving good results where the source is small compared with the optical system. When the source is large, as is often the case with street lighting lanterns, we have to use the flash method and this gives very good results if one is careful to take into account the brightness distribution across the source. In either case one needs a fair knowledge of solid geometry, particularly if the distribution is asymmetric, but no matter how good one's geometry may be—and here I am entirely with the author—there comes a time when you have to make some experiments. In this connection I was particularly interested to learn that the author has used scale models which are ten times full size. So far I have never found it necessary to make models more than full size and in some cases we have made small scale models to advantage where existing optical components of small size have been available.

The sodium lantern referred to is particularly interesting because it is probably the first to break with the box-like appearance of the conventional sodium lantern. Nevertheless, I wonder whether there are any disadvantages, particularly from the point of view of the performance of the lantern. For example, prisms facing the lamp are usually less efficient than prisms remote from the lamp, and if they do get dirty they may be very difficult to clean. In the conventional lantern the prisms are sealed-in against the bowl so presenting a perfectly smooth surface which can easily be cleaned: and such surfaces are usually easily accessible. Another point in connection with the lantern which the author has mentioned in the paper, is that he has tilted the lamp for two reasons, one aesthetic and the other technical. The tilted lamp, he says, avoids the risk of double peaking. But this is not really a risk—it is quite simple to devise a bank of prisms which will avoid this trouble. In addition, a tilted lamp will reduce the rate of run-back of intensity above the peak which aggravates glare and it is likely to make it quite impossible to produce a satisfactory medium angle beam lantern even 50 per cent bigger in width.

Also mentioned in the paper are lanterns using specially shaped diffusing envelopes which are designed so that the projected area produces the required light distribution. This method of control is rather crude and I hope that such lanterns are not intended for serious street lighting at normal spacings. The reflector lantern for mercury fluorescent lamps is of good appearance but one wonders once again what limitations in performance have had to

be accepted. It appears to have a distribution which lies somewhere between the medium angle beam distribution and cut-off. It would, of course, be expected to produce very little glare but the snag surely is that you have to close up the spacing somewhat if you are to avoid a patchy result in the street. Perhaps Mr Stevens would indicate what spacings are recommended for this lantern. With regard to the optical system, I wonder whether the type of facets used in the over-reflector in this lantern are really adequate to reduce the downward light to a sufficiently low value to produce a reasonable beam shape for street lighting purposes. One commonly finds in a lantern of this general type, where you have a large over-reflector taking perhaps a quarter of the lamp flux, that the downward intensity tends to be comparable with the intensity in the normal peak direction. One has to take special care to avoid this and I would like to know if the author has solved this problem entirely to his satisfaction. I wonder if the author could tell us whether this type of optical system is sensitive to variations in phosphor density. A recent survey of MBF lamps made by various manufacturers has revealed a difference in maximum brightness (seen in the direction of the arc) of more than 2:1. Presumably this will affect to some extent the performance of the lantern.

Mr J. B. Harris: I have always considered it a most unfortunate fact that, although our lamp research engineers have never slackened in their efforts to improve the efficiency and performance of electric lamps, efficient light control methods are often disregarded either due to a lack of technical appreciation or in the interests of aesthetics. Architects, whose responsibility in the field of lighting seems to grow year by year, seem to be happy to disperse their lumens with gay abandon and a complete misunderstanding of the purpose and meaning of light control. In the lay field, light control is not always popular; it is frequently misunderstood since it is thought by many that the best thing to do if you are not getting enough light is to remove the diffuser. Now the architect quite rightly is concerned with the external form of the illuminant, but his brightness pattern depends very much upon the means and efficiency of light control adopted. Thus the lighting engineer should be very firm in regard to the specific requirements of his lighting equipment, particularly if it is being designed for special purpose use.

In regard to specular reflectors for use with fluorescent lamps there is quite an important field, maybe not very extensive, concerned with the problems encountered in art galleries. After the war we carried out a certain amount of gallery lighting with the material that was then available, mirror glass. I recently inspected these reflector fittings and their condition was perfect since they can easily be cleaned and returned to their former performance. There is, however, the question of expense and weight, and so we return to the subject of aluminium. I have seen all the types of aluminium that the author has dealt with and although you can get good commercial grade aluminium I still feel that the use of super-purity quality having the characteristics of a B.S. 1615 Grade 1 reflector is still preferred. In some of the jobs in art gallery lighting you may get throws up of up to 30 ft. Thus you want the best performance possible, a performance that can be retained throughout the life of the reflector. I have always found considerable difficulty in obtaining a 5 ft. long trough reflector formed from 99·99 per cent purity aluminium and suitably treated, as one finds that apart from the question of expense you cannot get delivery in a reasonable time; and very frequently the finished product has not the required uniform appearance.

The author has referred to the bowl silvered lamps which I think were available before the war, but I feel that some mention should be made of the ever-increasing range of low and mains voltage internal reflector lamps, some of which are of very great value in modern lighting techniques. We have, for instance, incorporated them in historic houses where you require to get strong directional lighting on a ceiling or a picture. Where there is no place to locate the actual fittings, small silvered lamps can be incorporated in the existing chandeliers. On the general question of internal reflector lamps I think it is high time that consideration be given to the preparation of an appropriate British Standard. It is an unfortunate fact that if one refers to the various manufacturers' catalogues one finds a variety of figures given for say the peak intensity of a 150-watt lamp.

The miniature low voltage reflector lamps have been very useful for show cases, and a recent development, which has not been mentioned, is that of a reflector lamp with a heat resistant glass. It is a development arising out of an existing type of control principle, plus the use of a special heat resistant glass. This enables you to use them with waterproof and watertight lampholders for exposed garden lighting and underwater lighting effects.

There is another type of reflector bulb that has been applied to the 250 and 400-watt mercury vapour fluorescent lamps, which is a similar idea to that being adopted for the internal reflector tubular fluorescent lamp.

Regarding new developments, I have been rather

surprised that there has been no progress in this country with an American product, known as 'Fota-Lite' glass. This is really egg-box louvre control within glass and has the great advantage of easy cleaning. I am wondering why there has been no development of this material in this country—perhaps it is too expensive.

There seems to be in America another light control material referred to as a glass fibre polarizing light panel which is supplied in sizes of up to 2 ft. × 4 ft. and gives virtually glare free light from any angle. I wonder whether the author can give us any information on this material.

MR T. D. NARRACOTT: Mr Stevens has given us quite an amount of material on the plastics used and their effect on design. I was a little surprised to find that he mainly kept his remarks to street lighting when I should have thought the impact of this material on commercial fittings was just as great, if not greater. He rightly stresses the temperature limitations, but if one looks to this it is undoubtedly true that plastics have come to stay, and I would like to have his opinions on whether he feels that the future of this material is probably greater in the commercial field than in the street lighting field. I feel the author might have mentioned that this material may not be a very good one from the fading point of view, especially if used with mercury lamps. From experience I think it fair to say that a very strong warning should go out that materials of this type should be very carefully chosen before being used, especially with the mercury-type lamp.

I would also like to have heard a little more of the methods of controlling light from fluorescent fittings, not so much on the reflector side, but on the side of, say, refraction. The common sort of fitting we have today is the egg crate which is put up to shield a bare lamp and give a certain diffused area, but this has very little positive control of light in the sense that you are sending the outgoing light of the fitting in the direction that you want it to go. I think also we might have heard something on modular ceilings and illuminated ceilings, because here again I feel that plastics are probably well to the fore. In dealing with plastics, I think that one also ought to say that the design of moulds is extremely intricate and due consideration should be given to what happens with the bits and pieces that come out of the moulds because we have found in practice that a lot of distortion could take place unless careful attention is paid to the components as they are removed from the mould.

Dealing with aluminium reflectors, we have had a lot of talk about high quality reflectors and some of even higher quality called super purity. There is a point here which designers should bear in mind. Mr Harris says that his reflectors come up clean and that they give more or less the same performance as new, but I think a lot of maintenance people will know that the cleaning of reflectors does not take place very often, especially when they are up 30 ft. or probably even higher from the ground where maintenance does become a real difficulty. If, therefore, one is going to put in a very expensive material one must use that material, otherwise it becomes no better than its cheaper counterpart.

In the paper there is a sentence about the accuracy of designing reflectors, pointing out that an error of 1° in the reflector could give 2° or more in the beam. This does bring up a point which I feel is vital, and this is that the design and manufacture of the reflector can all be thrown away if the lamps themselves are not properly made. I think many of us will have had lamps and put them in fittings and then they turn round eccentrically when you screw them in; if you have lamps of that kind you cannot blame the fittings manufacturer if you do not get the performance that he states the fittings will give. I think people should bear in mind that if they buy the expensive fittings they should not put into them lamps which are so inaccurate that it is impossible to get a good performance.

Dealing with floodlights, we have heard once again about the reflectors, and there is also some mention in the paper on beam spread by a reflector system, presumably very complicated. I would like to hear the author's opinion on whether this in practice is a better method than putting in a spreader glass. I should imagine that the price must be greater than the spreader glass.

MR G. K. LAMBERT: My main interest is in street lighting and I would have preferred a paper centred on those aspects so that they could have been discussed fully. However, it is an extremely interesting paper. Some eight years ago I was involved, most reluctantly, in lighting a complete staircase from a remote point. Because of Fire Regulations we had to light the emergency staircase of 8-storey flats from a point outside. We had to throw a narrow band of light to cover the 3 ft. square window on each landing and at the same time screen light from the adjacent balconies which were private. The arc of the 400W MA/V lamp proved to have suitable dimensions and the strip of light extended over the eight storeys from the set-back distance we were permitted.

The flux method of design and the flashed area method seem to me to be related in much the same way as the corpuscular and wave theories of light:

both have their difficulties and both their uses. The flux method is certainly full of pitfalls. The flashed area method is particularly suitable for tubular fluorescent lamp reflectors. A former colleague described the application of this method to tubular lamps (A Polar Distribution Predictor: H. V. Shurmer, Transactions **25**, 81, 1950): he made up a set square which facilitated the prediction of light distribution from a single curvature reflector design. The method is not necessarily a graphical one and nowadays a digital computer could readily be programmed to check a design extremely accurately, taking account of the brightness variation across a lamp.

The flashed area method makes it clear not only that the peak intensity is controlled by the projected area in the direction of the peak intensity but equally important that the rate of cut-off above the beam depends on the ratio of distance between source and reflector (or refractor) and the size of the source. Prisms facing the lamp have the advantage of permitting a faster cut-off for a given value of this ratio.

The new 200-watt linear sodium lamp is welcome as much for its small cross section as for its increased efficiency in production of light.

One important aspect in the design of a refractor for high brightness sources is that it should be flashed generally and not brightly in a small patch.

A noteworthy development on which I should like to hear Mr Stevens' views is an American louvre system with specular louvres which are not flashed in the normal direction of view.

MR J. M. WALDRAM: I felt that the author did not deal adequately with the tolerances which his designs require. If you make reflectors to provide accurate light control, everything throughout the system has to be made and located with commensurate accuracy, otherwise during the life of the equipment the light will go somewhere else. An example is the sharp cut-off headlight which was very much favoured on the Continent. I do not think the designer has done his job if he merely employs a G.L.S. lamp, made for situations which do not call for precision, and does not specify the performance which his equipment demands. For precisely designed equipment the prefocus lamp may be necessary—you can get accuracy if you are prepared to pay for it.

My other point related to the formula shown by the author. Since I_θ is flux divided by the solid angle, the formula can be written $F=B_s\omega$, which I find an invaluable concept in dealing with axially symmetrical systems such as projectors, and I commend it to students.

MR H. R. RUFF: Both the flashed area-source brightness and the flux methods of optical design are useful but I agree that generally the former method is more often required. Has not the author, however, oversimplified the formula, since in any reflecting system the source brightness is not constant but is increased by reflectances within that system? Larger area low brightness sources are more greatly affected.

He has demonstrated the accuracy with which prisms can be made but often sees such prisms used fairly close to large light sources. Does the author in his experimental designs always cross check using light sources of the final dimensions?

MR A. G. PENNY: On a small point of information answering Mr Harris. I am happy to be able to tell him that the relative B.S.I. committee decided at its last meeting to undertake work on the preparation of a British Standard for reflector lamps.

THE AUTHOR (in reply): When preparing this lecture I was rather dubious about putting in the section on the fundamental basis of light control, but it seems to have created quite a bit of interest. Mr Ferguson refers to it as the 'flash' method. I think I still prefer to talk about the 'brightness' method because it then covers design of diffuser systems and systems which employ diffused reflectors, where of course talking of flashing is somewhat meaningless. Mr Lambert pointed out, and I agree, that both methods, the flux method and the brightness method, are equally valuable, but the reason why I put in this simple formula (which as Mr Ruff said, is not strictly true as I have tried to indicate in the paper) is that it is a simple way to help correct the misunderstandings of the people mentioned by Mr Harris who do put up those rather impossible problems in matters of light control.

Mr Ferguson referred to the injection moulded lantern and asked how the prisms are kept clean. In fact we have found in the three years we have had the lantern available that with the sealing system used, the interior has kept clean in the filthiest of locations, so we have had no problem of deterioration due to dirt. He mentioned the point of double peaking of the lamps due to the double arc tube. I do not really claim much for tilting a lamp except that it does give a new freedom to the design of a light control system, the fact that your control system does not necessarily have to be parallel to the axis of the source. With regard to the reflector lantern, tests have shown that in fact we can achieve reasonable spacing; the peak is high enough to allow use in the normal 120 ft. spacing.

On the question of the facets on the top of this reflector, the facets are in fact put in with a separate coining operation after the facet is pressed so we do achieve the necessary degree of accuracy. With regard to variation in phosphor density in the source this will, of course, have an effect on performance, but there is no reason to suppose that the reflector system described is more sensitive in this respect than any other system.

Mr Harris mentioned the value of super-purity aluminium, which, as he says, is an extremely valuable material. The difficulty of using it for a trough reflector for a fluorescent tube is its extreme softness, which probably means that one has to use a thicker sheet to get a sufficiently robust reflector, and again that puts the cost up. The magnesium alloys do give an alternative which is of some value where you want a little more robustness in the unit. Mr Harris also mentioned two developments we have heard of from the U.S.A. The 'Fota-Lite' glass, which I think goes back quite a few years now, is, I believe, something that depends rather on the development of the glass maker; manufacturers in the country evidently do not consider it worthwhile. The other thing he mentioned is the polarizing panel, which does not appear to do anything very striking.

Mr Narracott suggested that the emphasis of the paper was on street lighting but that was not really intended. I agree with him that there is certainly a field for the use of acrylic refractors in interiors, but it must be remembered that in street lighting the problem you have to meet is clearly defined; you have a fixed distribution you are wanting to achieve and your light source is pretty well standardized. You have a standardized problem which allows a standardized solution. In interiors that is not true; one has all kinds of sources of different sizes and all sorts of lighting problems to meet and it is in this instance difficult to see that a volume of products which meet the requirements of any particular one justifies tooling to the extent called for with this type of injection moulding component. He also mentioned a point covered in the written paper which I did not talk about and that was the use of a reflector instead of a spreader glass. The advantage of using a reflector is that one can have a certain amount of adjustment; with a spreader glass you are fixed with a certain amount of spread and you can only alter that by changing the glass—although I recall that Mr Waldram has described other methods where you can put two spreader glasses together and alter the degree of spread by changing the relative orientation of the two pieces.

I agree with Mr Waldram that the tolerances of these light control systems are really the important thing. There is more lighting design work and engineering in this than in the control system itself. With regard to the point that Mr Ruff made on the question of tolerances, I think perhaps there is a distinction between the tolerances on the prism and the fineness of detail. On an injection moulding component where you can get down to fine detail the important thing is the limitation of the width of the root between two adjacent prisms and also the radius of the tip. Obviously, in many ways one can simply sub-divide the prism if one wishes to make the detail fine, but there is a constant factor with the radius on the tip of the prism. As your prism gets smaller and smaller this tip radius becomes relatively larger, and in the smaller prisms it does become predominant.

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Current Applications of Electroluminescence

By P. W. Ranby, M.Sc., Ph.D., F.R.I.C., and P. J. Clewer, M.Sc.

Summary

This paper describes the construction of electroluminescent lamps using ceramic enamelling techniques and compares their properties with the more familiar electroluminescent lamp which employs organic dielectric materials. These 'ceramic' lamps lend themselves to applications where a low brightness source of robust construction is required together with a long life, for example, instrument lighting as in motor-car dashboards, electric clocks, telephone dials, etc. The 'organic' lamp is already used for aircraft signs, but digital indicators and other indicator panels can be constructed. The 'organic' type can also be combined with photoconductive materials to provide a number of interesting devices such as 'optrons', and image intensifiers and converters, and the X-ray image conveter is a particularly promising application. Some new phosphors which show a marked D.C. electroluminescence when used in ceramic constructions are described.

Introduction

Many things which now contribute to our general standard of living could only be developed provided light sources of the right type were available when required. Perhaps it is controversial to suggest that the lighting industry is the real benefactor which has made possible such social reforms as the shorter working week and holidays with pay, but certainly its contributions have been most important and unlike so many other aspects of progress do not lend themselves to misuse in the humanitarian sense. The achievements of the lighting industry are largely due to an early and continued appreciation of the value of active research. It is not surprising then that electroluminescence[1] as a possible new light source aroused great interest when its technical exploitation was first demonstrated about ten years ago[2], and that subsequently a number of reviews on the subject would appear[3,4,5]. Of these, the one by Bowtell and Bate presented to this Society in 1955 is of special interest because of its completeness of treatment of the subject up to that time from the illuminating engineering point of view. Since then, the major developments have been almost entirely in the application of electroluminescence, and consequently it is intended here to deal mainly with current applications and to avoid where possible repetition of those aspects which have been previously described.

In its broadest sense electroluminescence can be defined as the adiabatic emission of light by certain substances when placed in an electric field. The property can be shown by applying an alternating field to a thin layer of an electroluminescent material sandwiched between flat electrodes, one of which is transparent to light. Such a device is a luminous capacitor. The development of this laboratory phenomenon into a commercially available light source depended on the availability of a transparent conducting material, and the advent of electrically conducting glass[6] is a most important factor in the exploitation of electroluminescence.

Another major advance in the technology came about by the use of ceramic enamels in the fabrication of these light sources[7]. Immediately this technique gave electroluminescent lamps a degree of durability unsurpassed by any other artificial light source, and at the same time enormously increased the possible range of applications and physical dimensions. Still more recently the use of transistor circuits has provided a means of using electroluminescent panels in a much wider field and in turn has provided a further stimulus to their application.

By combining electroluminescent and photoconducting properties some most interesting devices can be produced and such developments open up still further applications.

Electroluminescent Materials

Although a number of very different binary substances such as gallium phosphide[8], boron nitride[9], and certain forms of silicon carbide[10], show electroluminescence, only the zinc sulphide phosphors are of any present importance and these are basically the same as the materials which were first used in demonstrating the phenomenon[1]. This is in marked contrast to the development of the fluorescent lamp where new phosphors have provided many of the discoveries by which progress has been made.

The authors are with Thorn Electrical Industries Ltd. The manuscript of this paper was received on February 1, 1960. The paper was presented at a meeting of the Society, held in London on March 8, 1960.

Electroluminescent zinc sulphides are prepared by heating a mixture of pure precipitated zinc sulphide with copper compounds and suitable fluxes, to temperatures of the order of 1000° C. in a non-oxidising atmosphere. When the product is cool, it is washed for example with solutions of acetic acid to remove zinc oxide, and with sodium cyanide to remove excess of copper compounds, dried, and then appears as a soft buff-coloured powder. The electroluminescent properties depend on the proportions of copper and halide ions incorporated in the zinc sulphide matrix; phosphors which emit in the green contain slightly more copper and appreciably more halide ions than those which emit in the blue under similar conditions of excitation. If about 1 per cent of manganese as a suitable compound is present in the mixture during the phosphor preparation, a yellow electroluminescent material results. The beneficial use of very small lead additions to the phosphor mix before the firing process has been described[11]. The copper concentrations used in electroluminescent sulphides are several times greater than in zinc sulphides prepared for optimum excitation by ultra-violet or cathode rays.

As in the preparation of other phosphors, very pure starting materials are necessary and careful control of the heating process is essential in order to obtain the brightest phosphors.

Electroluminescent materials emitting in the red can be obtained by using selenides in place of, or together with, sulphides during the preparation[12], but these materials are not of comparable brightness under the same conditions of excitation as the conventional blue, green, and yellow materials, and in addition, the use of selenium compounds has never proved attractive to the phosphor chemist on account of its toxic character.

Electroluminescent Lamps

For convenience, electroluminescent lamps can be divided into two main groups depending on their mode of construction and loosely called 'organic' or 'ceramic'. The former employ an organic layer in which the zinc sulphide phosphor is embedded, while in the latter the phosphor is held in a ceramic enamel layer between the two electrodes. Both types are of importance because they do not have complete interchangeability of characteristics, so it is intended here to deal first with the ceramic lamp and its application, and then with the organic types of construction and the various developments which are possible.

Preparation of ceramic electroluminescent lamps

A diagrammatic representation of the coatings involved in the preparation of a ceramic electroluminescent lamp is shown in Fig. 1. After careful cleaning and surface preparation, a thin sheet of good quality enamelling iron is coated with a layer of a ceramic frit and this is fused on to the plate. The function of this layer, or ground coat, is threefold; it must form a perfectly adherent layer to the iron plate, it must have a high dielectric constant, and it must be white and so act as a light reflector. This enamelled layer is about 0·002 inches thick and must be free from pinholes, and uniform over the whole plate. Any irregularities in this layer can cause differences in field strength in the final electroluminescent lamp, and this causes local irregularities in the uniformity of the light output. Ceramic enamels combining all the properties required for this coating are not usual in the enamelling industry and specially formulated materials are used[13].

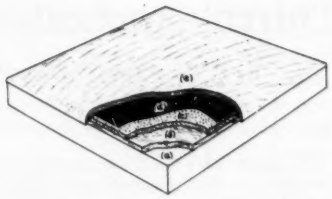


Fig. 1. Diagrammatic representation of the construction of a 'ceramic' electroluminescent lamp.

The phosphor is now applied in a layer about 0·001 inches thick to this coated plate. This phosphor layer consists of finely divided phosphor particles and another ceramic frit such that after heating it forms a perfectly adherent layer to the ground coat. The properties of the ceramic frit used in this layer are somewhat different from those of the ground coat. For example, the fusion point should be lower so that during the firing of this coat, there will be no appreciable tendency for the ground coat to soften and alter the uniformity of the original coating. Even more important, the phosphor bearing frit must be free from any harmful impurities which will cause loss of brightness of the phosphor; this is important because sulphide phosphors generally are very susceptible to poisoning by foreign metal ions and especially when used in enamels[14]. In addition, this frit must be non-conducting and transparent after firing. As with the ground coat this phosphor-enamel layer must be uniform in thickness, otherwise irregularities

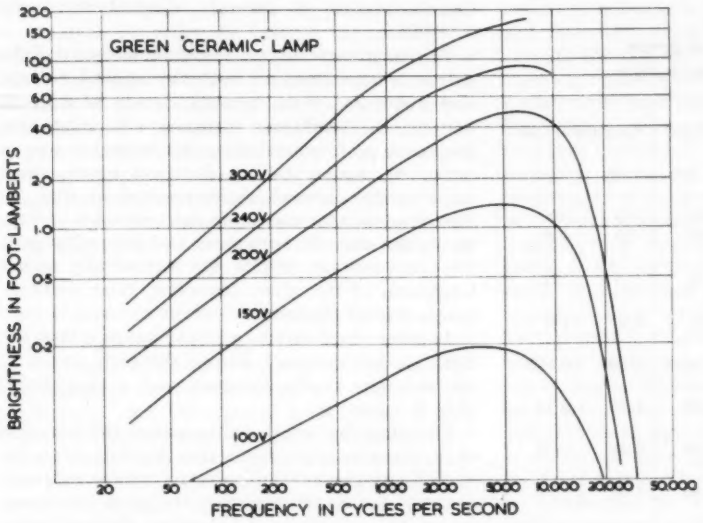
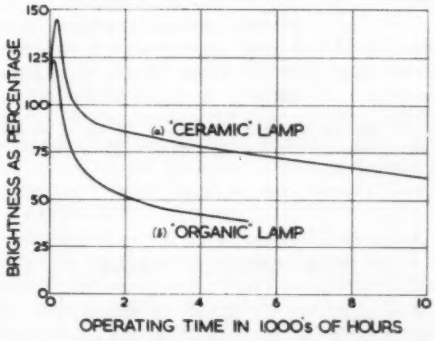


Fig. 2 (left). Effect of frequency on light output of a green 'ceramic' electroluminescent lamp at different voltages.

Fig. 3 (below). Brightness maintenance curves for green electroluminescent lamps operating at 350 v. 400 c.p.s. (a) 'ceramic' construction, (b) 'organic' construction.



appear in the finished lamp as areas of different surface brightness. The upper surface of this layer is made electrically conducting, by, for example, spraying the hot plate with a solution of a tin salt. This conducting layer should have a resistance of not more than a few thousand ohms per square, and at the same time should be as optically transparent as possible. A narrow region of the conducting film is removed from around all edges of the plate by sand blasting, aqueous electrolytic treatments, or simply cutting the conducting film with a diamond, and at this stage the plate will show electroluminescence if an electric field is applied.

Finally, the plate is coated with another ceramic frit which after fusing forms a clear protective glaze. This overglaze has to be specially formulated because its properties differ from those of the preceding frits; for example it is fused on to the plate at a lower temperature than that used for any of the preceding treatments, it must not affect the conducting film and must adhere uniformly to the whole surface of the plate. Also, it should have highly insulating properties so that the surface of the plate is electrically safe, and it should be transparent and colourless so that it does not materially reduce the brightness of the finished lamp. Uniform thickness of this glaze coat is not so critical as for the ground and phosphor coats. A small area of the conducting surface is not overglazed, and this is used for making electrical contact which can be affected in a variety of ways. Because electrical contact has to be made virtually to the front of the lamp, unless the contact can be made at an edge where it is not obvious, or is hidden by a frame or a surround, some method of camouflage such as overlay may be desirable. Electrical contact to the back of the plate presents no difficulty, and can be made either by spring contact or directly soldered lead.

The ceramic electroluminescent lamp can be fabricated in a great variety of planar shapes including circular and re-entrant angular forms. Curved surfaces present some difficulty because of the need for uniformity of each of the component layers in the construction, but this is not expected to be an insurmountable problem in the near future, and needle-like objects, such as instrument pointers, can already be made.

Table 1

Characteristics of green electroluminescent lamps

Characteristics	Ceramic Type		Organic Type	
	(*a*)	(*b*)	(*a*)	(*b*)
Voltage	240	350	240	350
Frequency (c.p.s.)	50	400	50	400
Brightness, foot-lamberts	2·5	20	3	22
Current, mA per sq. inch	0·125	1·6	0·2	1·6
Capacity, μF per sq. inch	0·0017	0·0021	0·003	0·003
Impedance, $M\Omega$ per sq. inch	1·92	0·22	1·15	0·14
Power Factor (cos φ)	0·15	0·48	0·28	0·39
Efficiency, lumens per watt	0·8	0·65	1·55	0·70

Characteristics of ceramic electroluminescent lamps

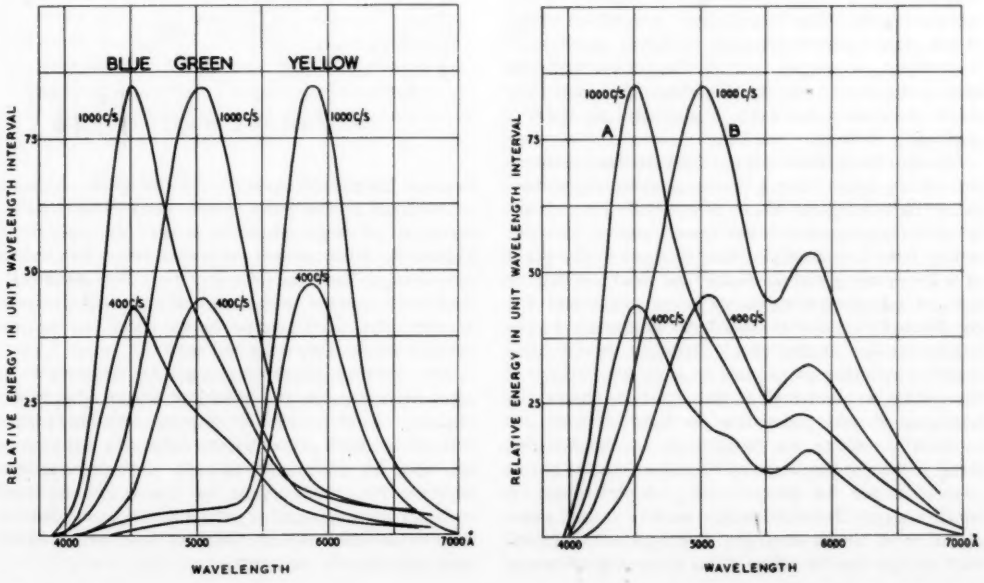
The brightness of an electroluminescent light source is dependent on both the applied voltage and frequency. With 'ceramic' lamps at a given voltage, the brightness increases with increasing frequency up to several thousand cycles per second before decreasing due to electrical losses which occur in the plate at higher frequencies (Fig. 2). The frequency for maximum light emission is practically the same for both green and yellow lamps at the same voltage despite the intrinsically higher brightness of the green phosphor; blue 'ceramic' lamps behave similarly.

Another characteristic of these lamps is that the light output increases during the early hours of life and then slowly decreases over a long period (Fig. 3, curve (*a*)).

Electrical characteristics depend on the thickness of the layers in the construction. Typical values for an ordinary green ceramic electroluminescent panel designed for mains operation are given in column (*a*) of Table 1; the corresponding characteristics of a panel designed for operation at higher voltages and frequencies in column (*b*).

Although the only phosphors which have sufficient brightness for commercial applications are

Fig. 4. Spectral energy distribution curves of 'ceramic' electroluminescent lamps at 400 and 1000 c.p.s. (350 v.) (a) using single phosphor components. (b) using mixtures of (A) blue and yellow phosphors, (B) green and yellow phosphors.



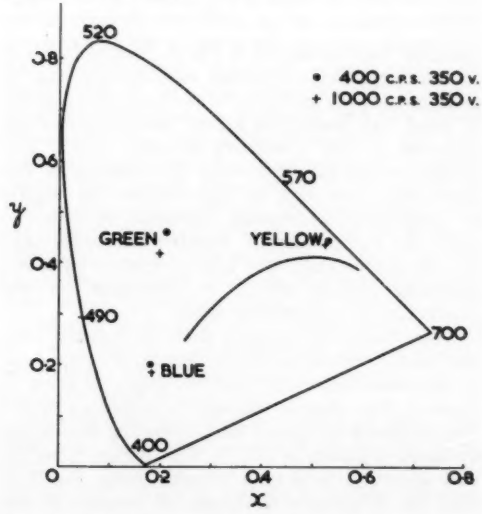
blue, green and yellow, a wider range of colours can be obtained by using the cascade excitation of a suitable organic fluorescent paint. In this way pink and reddish colours can be obtained. Alternatively, mixtures of the standard phosphors can be used, and the spectral energy distribution curves of ceramic electroluminescent lamps operating at different frequencies and using single phosphor components and mixtures are shown in Figs. 4 (*a*) and (*b*). The chromaticity co-ordinates for lamps using single phosphor components are shown in Fig. 5.

Uses of ceramic electroluminescent lamps

Electroluminescent lamps are not a substitute for conventional forms of lighting such as filament and discharge lamps, and it is only when this is appreciated that the present possibilities of this form of illumination can be fairly assessed. It provides a means of illuminating an area at a relatively low but uniform brightness in circumstances where the spatial requirements of the lighting system must be kept to a minimum.

In particular, ceramic electroluminescent lamps lend themselves to applications where a surface is to be illuminated at a low brightness level and a long life is necessary, as for example in electric clocks, electric light switch surrounds, and so on. In such applications the power consumption is negligible, and the thin planar nature of the light source does not involve any outward changes in the shape of the article. These lamps may be easily and smoothly dimmed to extinction simply by varying the applied voltage, and operate instantaneously upon application of the required potential.

Fig. 5. Chromaticity co-ordinates of blue, green and yellow 'ceramic' lamps.



One of the most interesting applications is for the illumination of instrument dials especially for the transport industries. This is possible by using a transistor to provide an alternating supply for excitation of the electroluminescence. A suitable power pack operating from a 6 or 12 volt battery consists of a ringing choke transistor oscillator giving an output of the order of 200 volts and 200 cycles with sufficient power to operate about half a square foot of ceramic electroluminescent plate. Such a unit is relatively cheap and reliable. The usual instrument markings are applied either by silk screening techniques directly on to the panel or as an overlay, and are visible in the normal manner during daylight hours but only the figures or markings emit light during darkness. Instrument pointers can be either self electroluminescent or silhouetted by a luminous background. The lighting of car dashboards by this method is already available in the U.S.A., and is being actively evaluated in this country.

Because the conducting film on the phosphor enamel layer can be easily cut and made electrically discontinuous it is possible to engrave a ceramic electroluminescent lamp before glazing and then, provided suitable contact points have been left, various portions of the plate can be illuminated to make signs for use in dimly illuminated situations.

The rugged nature of a 'ceramic' lamp can be used to advantage in constructing signs which are operated by an impact switch in a battery-transistor supply circuit. Self-contained units such as these can be used, for example, to indicate emergency exits in aircraft, and are of course independent of the main electrical supply.

Of the many suggested applications for ceramic electroluminescent lamps, domestic night lights and road signs are already in use in America, and it is probably not unreasonable to expect a demand for ceramic electroluminescent panels for the exterior of curtain walled buildings for situations where ordinary architectural panels would normally be used.

Five years ago it was thought[5] that one of the most prominsing applications for electroluminescent panels would be for photographic purposes such as dark-room safe lights and reflex printing. The 'ceramic' lamp would appear to be even better for these purposes than the earlier glass constructions but has been disappointingly received so far.

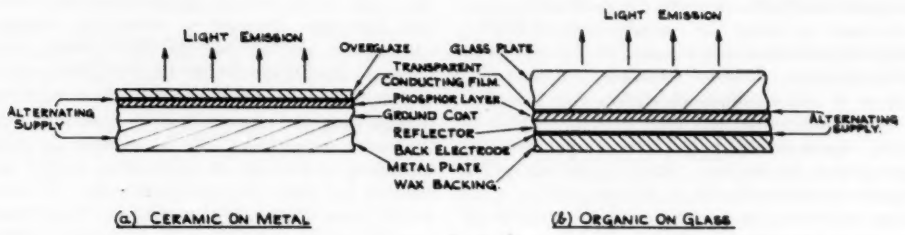


Fig. 6 (*above*). *Comparison of the construction of* (a) *the 'ceramic' and* (b) *the 'organic' types of lamp.*

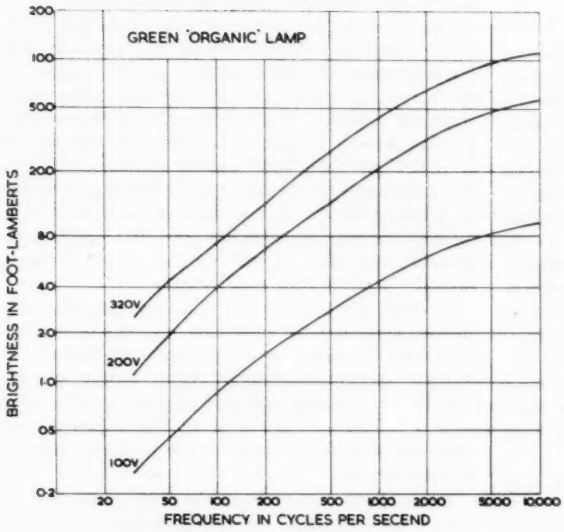


Fig. 7 (*left*). *Effect of frequency on light output of a green 'organic' electroluminescent lamp at different voltages.*

Preparation of organic electroluminescent lamps

The construction of some types of electroluminescent lamps using organic dielectric materials has been described in a previous paper[5]. In modern constructions the phosphor and a light reflecting powder are held in organic resins on a glass base which has a conducting transparent film on one surface. This conducting surface is first coated with the phosphor layer, followed by a layer of barium titanate[15], which serves to scatter light forward out of the lamp and to increase the overall dielectric constant so that more power can be applied to the lamp. Finally, an electrode of either evaporated metal, or conducting paint is applied to the back. This type of lamp requires very careful sealing to prevent the entry of moisture as this causes dielectric breakdown, and so the back is usually coated with paraffin wax and layers of aluminium foil to act as moisture barriers. A comparison of this type of construction with the 'ceramic' lamp is shown in Fig. 6. Special types of conducting paint containing lead dioxide can be used for the back electrode[16] and have the property of being 'self-healing' if a local breakdown of the dielectric occurs. These are suitable for 50 cycle operations and for small areas up to 400 cycles, but large areas operating at high frequencies require an evaporated aluminium electrode in order to carry the higher current. Painted electrodes have the advantage that they can be applied by a silk screening process which is convenient for the production of complicated areas.

These lamps are brighter than the ceramic type but have a shorter useful life (Fig.3). A comparison of the characteristics of the two types are given in Table 1. The effect of changes in frequency on the light output from a green lamp operating at different voltages is shown in Fig. 7. This differs from the corresponding curve for a 'ceramic' lamp (Fig. 2) in that the brightness continues to increase at fre-

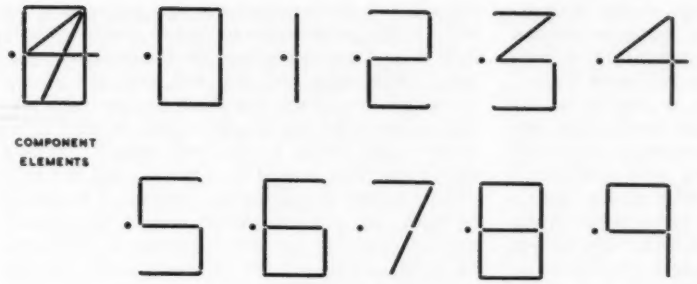


Fig. 8. Elements involved in an electroluminescent digital indicator, and the slightly stylized digits 0 to 9 which result.

quencies above those at which the ceramic lamp starts to decline in brightness. The upper limit of frequency, and hence maximum light output, is determined by overheating in the lamp which occurs at these high frequencies.

Another important difference between these two types of electroluminescent lamp is that because one is virtually the reverse of the other from the point of view of the construction (Fig. 6) the glass organic type is usually more suitable for small or complicated areas because the problem of making electrical contacts is simpler than for the 'ceramic' lamp.

Uses of organic electroluminescent lamps

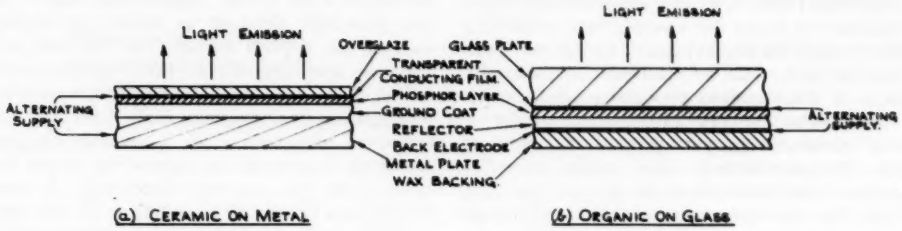
By shaping the back electrode into letters or symbols, almost any legend can be displayed by this type of lamp. Outstanding features of this type of sign are that they have a low power consumption, the legend is invisible when the lamp is off, and they are light in weight and occupy little space. Consequently, such signs are finding wide use in aircraft, especially as the available supply frequency of 400 cycles gives adequate brightness. Electroluminescent indicator panels can be constructed to replace assemblies of indicator lamps for switchboards. A typical unit is a 3-inch square plate less than 0·25 inches thick, and providing over 100 quarter inch squares each of which can be individually illuminated. Each individual inch square lamp consumes only about 50μA and can have a mask to indicate a letter or number; alternatively, they can be made in special shapes by shaping the back electrode. In a similar manner very small illuminated areas, or dots, of about 0·010 inch in diameter can be constructed for use as time markers on ciné film, and also for special instruments where a small lamp consuming only a few micro-amps is required.

A further development is a panel in which the front electrode is divided into strips and the back electrode is similarly divided, but at right angles to the front[17]. When a voltage is applied between one of the front and one of the back strips, the area of intersection lights brightly with the two arms more dimly illuminated. These cross-arms can be suppressed by introducing a layer of a non-linear resistive material such as finely divided silicon carbide between the reflective layer and back electrode, leaving only the area of intersection illuminated. Such a panel has inherent stability of coordinates and so may have applications in computers and for long-persistence radar displays by replacing the conventional cathode ray tube. Resolution is limited by the width of the electrode strips and although 100 lines per inch can be achieved there are difficulties in making the individual contacts.

Many instruments use digital read-out systems and electroluminescent digital indicators[18] can be constructed which have the advantage over some other types of a wide viewing angle. The lamp itself is made of a number of separate strips and various combinations of these are illuminated to give the digits 0 to 9 in a slightly stylised but quite readable form, Fig. 8. To allow single pole switching to be used for selection of the digits, a coding matrix of non-linear resistors is built into the back of the lamp by a printed circuit technique and using finely divided silicon carbide. In this way the lamp has one common terminal and ten others, one for each of the digits 0 to 9. By applying voltage between the common and any given terminal the correct combination of lamp elements is automatically selected by the resistor matrix. The indicator together with its coding matrix has a thickness of only 0·4 inch, and can be used as single or multiple units with decimal points if required.

Other types of electroluminescent lamps

So far only the glass based organic and metal based ceramic constructions of electroluminescent lamps have been considered but there are other possibilities such as a glass based ceramic, and an all-plastic type. Glass based ceramic constructions



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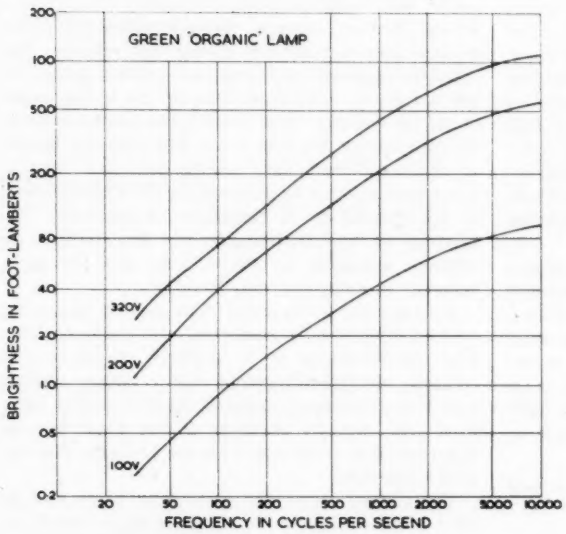

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These lamps are brighter than the ceramic type but have a shorter useful life (Fig.3). A comparison of the characteristics of the two types are given in Table 1. The effect of changes in frequency on the light output from a green lamp operating at different voltages is shown in Fig. 7. This differs from the corresponding curve for a 'ceramic' lamp (Fig. 2) in that the brightness continues to increase at fre-

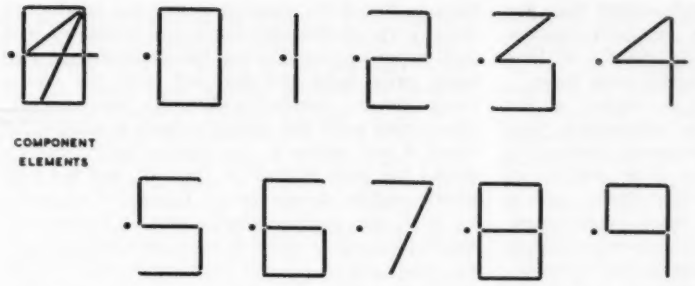

Fig. 8. Elements involved in an electroluminescent digital indicator, and the slightly stylized digits 0 to 9 which result.

quencies above those at which the ceramic lamp starts to decline in brightness. The upper limit of frequency, and hence maximum light output, is determined by overheating in the lamp which occurs at these high frequencies.

Another important difference between these two types of electroluminescent lamp is that because one is virtually the reverse of the other from the point of view of the construction (Fig. 6) the glass organic type is usually more suitable for small or complicated areas because the problem of making electrical contacts is simpler than for the 'ceramic' lamp.

Uses of organic electroluminescent lamps

By shaping the back electrode into letters or symbols, almost any legend can be displayed by this type of lamp. Outstanding features of this type of sign are that they have a low power consumption, the legend is invisible when the lamp is off, and they are light in weight and occupy little space. Consequently, such signs are finding wide use in aircraft, especially as the available supply frequency of 400 cycles gives adequate brightness. Electroluminescent indicator panels can be constructed to replace assemblies of indicator lamps for switchboards. A typical unit is a 3-inch square plate less than 0·25 inches thick, and providing over 100 quarter inch squares each of which can be individually illuminated. Each individual inch square lamp consumes only about 50μA and can have a mask to indicate a letter or number; alternatively, they can be made in special shapes by shaping the back electrode. In a similar manner very small illuminated areas, or dots, of about 0·010 inch in diameter can be constructed for use as time markers on ciné film, and also for special instruments where a small lamp consuming only a few micro-amps is required.

A further development is a panel in which the front electrode is divided into strips and the back electrode is similarly divided, but at right angles to the front[17]. When a voltage is applied between one of the front and one of the back strips, the area of intersection lights brightly with the two arms more dimly illuminated. These cross-arms can be suppressed by introducing a layer of a non-linear resistive material such as finely divided silicon carbide between the reflective layer and back electrode, leaving only the area of intersection illuminated. Such a panel has inherent stability of co-ordinates and so may have applications in computers and for long-persistence radar displays by replacing the conventional cathode ray tube. Resolution is limited by the width of the electrode strips and although 100 lines per inch can be achieved there are difficulties in making the individual contacts.

Many instruments use digital read-out systems and electroluminescent digital indicators[18] can be constructed which have the advantage over some other types of a wide viewing angle. The lamp itself is made of a number of separate strips and various combinations of these are illuminated to give the digits 0 to 9 in a slightly stylised but quite readable form, Fig. 8. To allow single pole switching to be used for selection of the digits, a coding matrix of non-linear resistors is built into the back of the lamp by a printed circuit technique and using finely divided silicon carbide. In this way the lamp has one common terminal and ten others, one for each of the digits 0 to 9. By applying voltage between the common and any given terminal the correct combination of lamp elements is automatically selected by the resistor matrix. The indicator together with its coding matrix has a thickness of only 0·4 inch, and can be used as single or multiple units with decimal points if required.

Other types of electroluminescent lamps

So far only the glass based organic and metal based ceramic constructions of electroluminescent lamps have been considered but there are other possibilities such as a glass based ceramic, and an all-plastic type. Glass based ceramic constructions

are similar to the organic lamps except that the organic resins are replaced by inorganic ceramic materials and the general characteristics of these lamps are between those of the two main types.

The all-plastic construction is similar to the organic on glass type, but the conducting glass base is now replaced by a transparent conducting plastic material. Unfortunately it is difficult to prepare an electrically-conducting plastic with a high optical transmission and which under operating conditions is highly impervious to water vapour or hydrogen ions, and consequently this construction is prone to dielectric breakdown and so the effective life is very short. Although the flexible and virtually unbreakable properties of an all-plastic construction are most attractive features, this version of the electroluminescent lamp must be regarded as of an experimental nature at this time.

Photoconductive-Electroluminescent Devices

Because of its low current consumption, an electroluminescent lamp is particularly suited to control by photoconductive cells of say cadmium sulphide. The simplest form of such a device consists of an electroluminescent plate and a photoconductive cell electrically in series with one another. When radiation falls on the photoconductive cell, it becomes conducting so that voltage is applied to the lamp causing it to emit light. Cadmium sulphide photoconductive cells are mainly responsive to the red end of the visible spectrum, infra-red, X and γ-rays, and corpuscular energy such as α- and β-rays. Since the photoconductive cell can be remote from the electroluminescent lamp the system can be used as a radiation detector, or warning device.

When an electroluminescent lamp in series with a photoconductive cell is arranged so that any light from the lamp will fall on the photoconductor and volts are applied in the dark, no light is emitted because the photoconductor is in a non-conducting state. If the photoconductor is now irradiated with light it becomes conducting, the electroluminescent lamp emits light and this will keep the photoconductor in a conducting state; the lamp will stay illuminated until the supply voltage is interrupted when it will return to the dark state[19]. Such a device has been termed an 'Optron', and is a type of information storage device. Instead of triggering by light, the photoconductor can be temporarily shorted through a suitable resistance to illuminate the lamp and so put the photoconductor into the conducting state. The triggering pulses and decay times of an optron are of the order of a tenth of a second. If these delay times can be reduced to microseconds such devices will be of use in computers. An interesting development along these lines is to use a number of such photoconductor-electroluminescent lamp units connected so that light from one falls on to the photoconductor in series with the next lamp. In this way a moving band of light is obtained, unfortunately the rate of movement, or scanning, is too slow to be of much practical value at present.

A more promising application of photoconductor-electroluminescent devices is for image conversion and intensification. In an intensifier, a weak light image is projected on to the back of the panel, and a much brighter image is seen on the front, the extra energy required being drawn from the electrical supply to the plate[20]. In a converter, the incident image may be formed, for example, by infra-red, or X-rays, either with or without energy gain.

A converter may consist of a conventional electroluminescent lamp but with a layer of photoconductor between the reflecting layer and the back electrode, Fig. 9. When the incident radiation is light, the depth of penetration of this radiation into a cadmium sulphide photoconductor is small, and it is necessary to rely on surface conduction

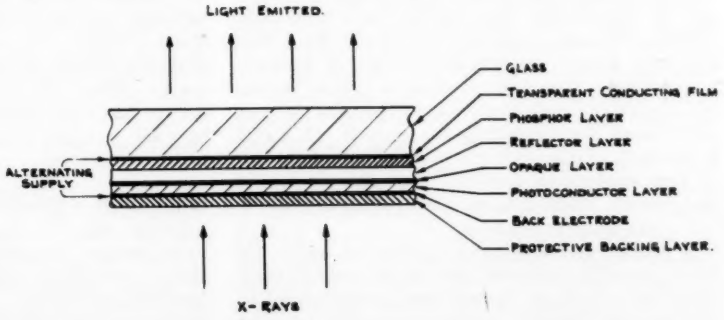

Fig. 9. Diagrammatic representation of the construction of an X-ray image converter.

and so the panel must be designed with this end in view, by, for example using a ridged photoconducting layer[21]. When X-rays are used to excite the panel their greater penetration enables continuous layers of photoconductor to be used which simplifies the construction, and also gives higher resolution of the image. X-ray image intensifiers of this type show a brightness gain of tenfold over a conventional fluorescent screen at X-ray dose rates of about 0·5 r/minute. The use of these panels is limited to stationary objects but, even so, are of interest to the medical profession.

Normally an extra optically opaque layer between the electroluminescent layer and the photoconductor is necessary to prevent light feedback, because this is liable to increase the amplification of the image at the expense of its stability and definition. By using a controlled amount of optical feedback, increased amplification can be obtained together with persistence of the image after the X-rays have been cut off. In this way, holding times of up to 45 seconds can be obtained which means that intermittent and therefore much reduced X-ray exposures may be used. These panels are also sensitive to γ-rays and fast electrons and in each case show a brightness gain over a conventional screen.

Electroluminescence Excited by Direct Current

In the construction of the photoconductive electroluminescent devices described above, the phosphors and photoconductors are held in organic media and the devices operate off alternating supplies. Certain manganese activated electroluminescent sulphides when applied in ceramic enamels to a conducting base are excited by d.c. Some of these show properties approaching those of organic constructions using combinations of phosphors and photoconductors.

The simplest of these phosphors is a zinc sulphide activated by copper and manganese which when made into a ceramic electroluminescent lamp in the normal manner emits yellow light when a d.c. potential of 100 volts or more is applied. This same lamp can be excited by a.c. and it then emits shorter wavelength radiation e.g. in the green or blue. In this way a colour changing panel can be constructed.

Another phosphor which can be excited by d.c. when used in a ceramic electroluminescent panel is a zinc cadmium sulphide activated by copper and manganese[22]. This material shows a d.c. electroluminescence when sensitized by electromagnetic radiation, cathode rays or X-rays. After the source of sensitizing radiation is removed, the cell continues to emit light for some time provided the voltage is maintained. If the voltage is switched off, and then reapplied in the dark, the cell is again available for sensitization. Such a device has properties similar to those required for X-ray intensification screens by combining the photoconductive, electroluminescent, and persistence properties, with the advantage of using only one sulphide component.

These d.c. excited ceramic devices are still in the early stages of development and much work has yet to be done before their ultimate role can be fairly assessed.

Conclusion

Although electroluminescence at its present brightness level is in no way a competitor with established general lighting techniques, it has great versatility and already provides a convenient means of illumination for certain applications. Just as electroluminescence is a relatively new means of providing light so also are the applications for which it seems most suited, and it is inappropriate to try to achieve by it, results which can be more easily obtained by existing light sources.

So far there have been remarkably few important phosphor developments other than the steady improvement of the known materials, but the fact that other substances show electroluminescence is encouraging. It may be that the discovery of new materials or methods of preparation will provide a similar great advance in the technology of electroluminescence to that which took place in early fluorescent lamp development when sulphides were replaced by other phosphors.

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Discussion

MR C. G. A. HILL: I would like to say first that this paper has been most impressive. The demonstrations have impressed everybody, I am sure, and I think the Society can congratulate itself that it has had a paper by the authors best qualified to give it to us on this subject.

I have been a little puzzled at the methods of making some of the electroluminescent lamps, and I would like to ask the authors if in fact the general method of applying the materials to the lamp is by spraying them on to the metal; or on to the glass in the case of the organic one? I think I am right in saying that the thickness variations of the electroluminescent sheet show up very sensitively as a brightness variation and on inspection of many panels there are local variations of brightness. I wonder whether there are other ways of applying the material which have been considered.

Secondly, I have recently seen a very thin flexible plastic electroluminescent lamp, originating in America, which could be cut with a pair of scissors rather than a pair of metal shears, and I wonder if the authors have any comments on the possible applications of this material.

MR J. M. BOWTELL: I think the authors are undoubtedly wise in concentrating on those aspects of electroluminescence which have a high chance of early success, and in electroluminescence, as you have seen, this means devices and sources 'to look at' rather than lamps 'to see by'. I had hoped that we would have heard more about the latter. Undoubtedly the lighting engineer could make very great use of a lamp in the form of a thin panel. It would need to have a good colour rendering, be adequately bright and use a minimum of gear, but if these conditions were satisfied then I think only a modest luminous efficiency would suffice—something in the order of 8 to 10 lumens per watt. If we could only get this, electroluminescence would soon become an excellent new lighting tool. About five to seven years ago this specification could not possibly have been met with electroluminescence. It seemed to be an inherently inefficient process, but there has been a considerable increase in our knowledge of the physics and chemistry of solids in the past few years in a wide variety of fields, and it is reasonable to expect that this might lead to increased electroluminescent efficiencies in the forseeable future.

Coming to the 'ceramic on metal' panels, of which we have seen such an excellent display, there was one feature of the construction which I feel needs clarification. This is that the steel back plate serves as one electrode and, of course, is connected to the supply. Presumably, therefore, it represents a shock hazard and raises problems of insulation. Is there any advantage in having a second electrode which is electrically isolated from the metal sheet backing?

Coming to the X-ray image intensifier, this seems to me to be a worthwhile line of application for electroluminescence. How does it compare in performance with the existing calcium tungstate intensifier, and how does it compare with the photo-electronic intensifier, descriptions of which we have seen in the literature from time to time? Perhaps I should add that in the photo-electronic intensifier the X-ray image is focused on a photo-emissive layer. Electrons are released, accelerated in an electric field, and are focused on to a fluorescent screen to form a corresponding visible image. Very considerable intensity increases can be obtained and the device has a very quick response time, therefore it reacts quite rapidly to movement.

The authors have not gone into the question of the history of the use of zinc sulphide phosphors in enamelling frits. This was started in the early stages of the war with the incorporation of the ordinary phosphorescent u.v. excited zinc sulphide phosphors in frits which were enamelled on to a steel lighting fitting. These were used for emergency lighting in submarines in the British and American navies during the war.

THE AUTHORS: In reply to Mr Hill, we agree that uniform coating is most necessary in the preparation of electroluminescent lamps. We have investigated many different methods of coating with varying degrees of success, but have found that spraying techniques are usually the most successful.

Regarding flexible plastic lamps, we have in fact seen some of these from America and they live up to their name in that they are certainly very flexible and they can be cut with a pair of scissors. It would seem that at the moment no plastic lamp has a life of more than a few hundred hours due to the water vapour transmission of transparent plastics. Water vapour is injurious to electrolumines-

cence and it has been found by experience that such lamps only last a relatively short time compared with other types. The plastic lamp will not be a commercial proposition until a new plastic material is available with at least a much reduced water vapour transmission so we await the researches of the plastics chemists with interest.

Mr Bowtell mentioned the use of photoluminescent sulphides in enamels for emergency lighting during the last war; in contrast the requirements for enamelling electroluminescent phosphors are much more stringent because additional factors such as the electrical properties, the thickness of the layers, and so on, have to be considered. With regard to the construction of ceramic lamps a separate back electrode apart from the steel plate complicates the construction; the emphasis of the present construction is simplicity and robustness and to depart from this would be to do away with some of the most salient factors. An electrical hazard due to the back electrode is overcome by coating the steel plate with a ceramic overglaze or with a suitable insulating plastic which makes it perfectly safe to handle.

Mr Bowtell also raised the question about using electroluminescence as a general source of lighting. This must have been one of the very early dreams of people who looked to the uses of electroluminescence; unfortunately it is nearly as far off as ever. Despite world-wide efforts to find new electroluminescent phosphors we are still relying on materials similar to those originally used by Destriau and these are still neither brought enough nor of sufficiently high efficiency for general lighting. Recently we have been able to increase the brightness of lamps by a factor of about two, but unfortunately the efficiency instead of going up has gone down to 0·75 lumens per watt and we are still a long way off the figure of 8 to 10 lumens per watt which would be required for general lighting on an economic basis. Present electroluminescent lamps are bright enough to light a room panelled with them, but the low efficiency and high cost on such a scale would be prohibitive. We feel electroluminescence at present is best suited to the types of application we have shown here tonight.

Comparing the X-ray image intensifier with a typical calcium tungstate or zinc sulphide screen, we have had in the extreme case brightness gains of about 100, though somewhat between 20 and 50 is a more average figure. The Physics Department of King's College Hospital have been co-operating with us on this project and have given us a great deal of help on the medical aspects. The performance of the amplifier is governed solely by the photoconductor which at present is a cadmium sulphide. This photo-conductor has its limitations such as a slow response time, and consequently these screens are not really suitable for viewing fast moving objects such as the heart or lungs but can be useful in certain operations such as bone surgery. The performance of this amplifier is below the photoelectric devices which have a gain of 1,000 or more with an extremely fast response time, but in favour of our type of panel is simplicity and cheapness. The electronic type of amplifier requires very elaborate auxiliary equipment and very high voltages are involved as opposed to the 800 and 900 volts of our own panels.

DR W. S. STILES: I was very much attracted to some of the properties of these ceramic lamps from the photometric point of view, their long life and robustness, and one wonders whether specimens might serve as sub-standards lamps for testing highly sensitive photometric devices such as photomultipliers and so on, using a variation of the applied voltage to reduce the brightness to an extremely low value. I would like to ask to what extent the characteristics of the lamps, such as colour, would remain constant in dropping the voltage, and whether the lamps could in fact be used as highly attenuated sub-standards of light.

THE AUTHORS: In reply to Dr Stiles, there is a use for these lamps particularly with photometers and where a standard of very low intensity is required. Recent measurements on plates with a photo-multiplier have shown that light is still emitted down to the noise level of the photomultiplier, i.e. well below the usual threshold of the human eye. In this respect these lamps can be useful where a very low level light source is required. Only changes of frequency, and not voltage, affect the colour of the lamp. By putting a resistor or condensor in series with an electroluminescent lamp it has been claimed that it will retain a nearly constant light output for four-fifths of its life.

MR J. F. PICKUP: I wonder if you would make some comment about particle size—whether consistently small particles are best or whether large particles are best. Also why some particles, of the same size, are more efficient than others so far as luminescence is concerned.

THE AUTHORS: It seems that large particles give more light and better life, but a lower efficiency in terms of lumens per watt than small particles. These effects are based on experimental rather than theoretical data. The variation in luminous effici-

ency of particles of the same size is associated with the difficulty of ensuring uniform processing of each particle during the preparation.

MR D. H. HOLLOWAY: Has any work been carried out on the reduction in life by embedding the phosphor in a frit or by heating in the case of the enamel panel which you discussed?

Secondly, I believe that work has been carried out in the U.S.A. showing that the life of most of the phosphors used corresponds to $10^{(10)}$ cycles. I see there is quite a recent paper on this, and I wonder if this is comparable with your own work?

I believe that the range of grain size used in electroluminescent panels only emit light from small points on the crystal. Is anything known about this for different sizes of grains?

I watched the demonstrations closely, but it still seems to me that electroluminescence is rather in the gimmick stage. Even now, most of the demonstrations you have shown, with the possible exception of the X-ray intensifier seem to be capable of being achieved more cheaply, and to some extent more reliably by conventional light sources. I wonder perhaps whether a little more research is not required into applications where you could only use electroluminescence to do the job.

The use of phosphors for pointers has rather intrigued me, and I believe that the speedometer is a high torque instrument which could carry an extra load due to the increase in weight of the pointer, but this is not so with some other instruments. In constantly rotating pointers, is the contact made by a commutator?

Furthermore, on cars I gather that you consider the use of an oscillator to be necessary. I would have thought that price is a very great question, but perhaps a.c. generation in cars might have some beneficial effect on that. Has any work been done on that section of electroluminescent panels?

THE AUTHORS: With reference to the ceramic type of lamp, the life of the phosphor can certainly be reduced if there are harmful impurities in the frit. As mentioned before, these frits have to be very carefully blended to meet the properties they must fulfil. Not only must they be harmless to the phosphor particles themselves, but they also have to match up to the co-efficient of expansion of the base material on which they are applied.

With regard to the figure of $10^{(10)}$ cycles of any frequency being a rough measure of the life of the lamp, this was given in a recent review where the calculation had been done. It is probably true to say that the lamp should last for $10^{(10)}$ cycles of any frequency of a.c. which is applied, and this may account for the apparent reduction in the life of the lamp at high frequency.

With regard to the position of the emitting points of light in powders, work on single crystals of zinc sulphide has shown that light is emitted in bands or points on such a crystal, and this is probably true of powder particles as well. In fact, theory demands that light should only be emitted from points, because the field strength observed in an actual lamp is not high enough to produce light from the whole volume of the crystal. This may account for the observed reduction in light output as the crystals are ground finer and finer.

We do not agree that many of the devices on display here are only gimmicks. For example the aircraft signs, which were our first commercial application, have been in production for nearly three years and many passenger airlines are using them. Aircraft manufacturers are very conscious of saving weight and power, and as time progresses there is more and more interest in these lamps for these reasons. The problems of instrument lighting can often be overcome more simply by electroluminescence than by any conventional method of lighting; similarly it is difficult to imagine any other method of self-illuminated controls for car heater panels or telephone dials, than by electroluminescence. Tests have shown that because of the long life and durability of the ceramic type of lamp under normal conditions they far exceed conventional light sources in reliability. We are continuously investigating new applications of electroluminescence. For example there is the interest previously mentioned for film marking lamps for fitting inside ciné cameras, and only with electroluminescence can you pack 30 lamps into a space of 10 mm. $\times$ 5 mm. It is also probably the only lamp which can emit light at a current of only 1 micro-amp.

For car dashboard applications the pointers are completely coated and symmetrical, but there is a certain increase in weight which in low torque instruments can be a problem. This is a question of instrument design and has already been overcome in the U.S.A. For continuously rotating pointers, a simple slip ring or commutator can be used. The current in such a pointer is probably a fraction of a milliamp, so there will be no trouble with the contacts due to sparking.

The idea of an a.c. generator in a car is certainly very attractive though a higher frequency than 50 cycles would be desirable. However, transistor oscillators are not complicated, and are available commercially for a matter of shillings. American cars are on the market with complete electroluminescent dashboard lighting using such power

packs, and it is possible that very shortly we shall be seeing it in this country as well.

MR J. S. PRESTON: I would just like to ask two simple questions. The first one which has already almost been answered, is a question on the brightness maintenance of the plates or lamps. If I may refer to the slide you showed, I presume that curve was for the lamp running continuously. What in fact would be the shape of the curve if you do not run it at all? In other words, how much of the deterioration is due to running and how much to 'natural causes'?

Secondly, what is the response time for such a plate if you give it a single pulse?

THE AUTHORS: The brightness maintenance curve shown was for continuous running. As far as is known the life depends only on operating time and there is no deterioration 'on the shelf' provided the lamps are stored under suitable conditions.

With regard to the response time, the rise of brightness usually occurs over the first two or three cycles of the applied voltage but some recent work using very low resistance gold films as the transparent conducting electrode and applying square-wave pulses to these lamps indicates a more rapid response time and in some cases the rise time can be as short as a micro-second.

MR W. THOMAS: I would like to ask whether this deterioration of the zinc sulphide is due to the decrease in the dielectric constant or is it due to the decrease in the properties of the zinc sulphide? I ask that because I have done a lot of work since 1940 on fluorescent materials in ceramics, using radium as the energizing source, and I have been struck by the similarity of the curve of the decrease in luminousity when using radium. Also, have you tried the effect of refiring the enamel after it has lost its luminance and have you got any luminance back?

THE AUTHORS: With regard to the deterioration in the brightness of lamps, as far as we know this is due to the zinc sulphide itself; water vapour, and possibly oxygen initiate this deterioration. This has shown up sharply in experimental lamps having no protective layers when they have a very short life. It may be due to electrolysis in some form because there is a darkening of the phosphor which seems most noticeable when water vapour is present. Possibly oxygen causes a slower deterioration.

Reheating of the ceramic type of lamp can produce an increase in light output especially if the lamp has been on test for some time. The similarity in the shape of the maintenance curves with those of radioactivity excited fluorescent materials in ceramics is interesting.

MR M. G. CLARKE: I would like to know whether you have done any work on simultaneous applications of a.c. and d.c. on the panels. A report of work in America suggests that rather higher efficiencies are obtained by doing that.

THE AUTHORS: If higher efficiencies can be obtained using mixed a.c. and d.c., it would be interesting from the theoretical point of view. Our own experience along these lines has not substantiated the American claim.

MR J. G. HOLMES: The reported life of the ceramic lamp seems to line up very closely with the life of luminescent and phosphorescent ceramics which have been mentioned earlier, and I would suspect that there is something in the nature of borate and silicate and similar ceramics and something in the nature of the zinc sulphide which determine the life rather than anything in the nature of the electroluminescent process. That leads me to say that one of the tests for enamelled iron sheet to see whether it is coated properly, is to put it in a tank of electrolyte and see how much current can be passed through it. I am a little horrified at Dr Ranby picking up these things which seem to have 400 cycles at 230 volts on them. I do not know what the I.E.E. Regulations are going to do during the next few years, but I do feel that the rest of the general public will need to be convinced that the methods of electrical protection which are applied to these devices will in fact stand up to the sort of treatment they may get in the garage or the nursery, or perhaps from the amateur lighting engineer who is putting in one for himself and whose screwdriver slips. What safety precautions are provided in the panel or in its electrical supply?

One other point—it has been suggested that it will be a long time before we get room lighting by electroluminescent processes. That may well be true, but where is the limitation? The efficiency of the lamps appears to be limited to fairly low figures, in lumens per watt, but surely the limitation is in the wattage. If one is going to get 1,000 lumens output per sq, ft. one has to dissipate over 100 watts per sq. ft., and the requirement then is an electrical device which will allow the power to be dissipated in the phosphor or in the dielectric itself. I would have thought it a fairly simple matter of arithmetic to calculate power loss, light output, and the temperature rise to see where the

limitations are. I would very much like to hear the authors speak on that subject.

THE AUTHORS: With regard to the ceramic plate which we cut in two as a demonstration, this was operating on the mains and had resistors built into the leads to reduce the current to below 5 ma. The demonstration was aimed at illustrating a property of ceramic electroluminescent lamps not possessed by other electric light sources. Resistors and, as previously mentioned, suitable insulation will of course be used on any lamps available to the public; the lamp itself will actually present less hazard than the actual wiring used for operating any electrical device. In fact, the lamp itself being of such a robust construction should stand up to the sort of treatment that Mr Holmes suggests they might get in the garage or the nursery even better than most devices.

Some aspects of the question on room lighting have been dealt with earlier. We have not made any exact calculations, but it is fair to say that the power required to illuminate a room would be too high. Also, it is not possible to produce a good white lamp at present, because an efficient red phosphor is not available. While some red electroluminescent phosphors have been made, they are not comparable in brightness to the three you have seen in the demonstrations under the same operating conditions.

MR H. W. WINDEBANK: In considering the question of increased brightness, is it not true to say it is a problem of finding a suitable material with the highest specific dielectric constant into which the phosphor is embedded? We cannot dissipate enough power in the layer because we cannot pass enough current through it in order to excite the powders, which are surely of comparable efficiency to those used in other fluorescent applications. Surely the limitation today is not so much the phosphor as the application?

THE AUTHORS: The brightness of a lamp certainly depends very much on the overall dielectric constant of the material which is a measure of the power which can be dissipated in the lamp under given conditions, and the higher the dielectric constant of the material the brighter the lamp. For this reason we incorporate certain titanates in these lamps, the titanate crystals have a very high dielectric constant. Unfortunately the powder has to be bound in a material of lower dielectric constant, probably less than 10, which reduces the dielectric constant from about 1,500 in the single crystals to a value of say 100 in a completed lamp. In the future it may be possible to cinter layers of such material, when the overall dielectric constant will be much higher.

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Additions to the List of Members

Fellowship

The Council has accepted the following application for Fellowship of the Society:

R. W. Stevens

Diploma Membership

The Council has accepted applications for the Society's Diploma in Lighting Engineering from the following, who are now Diploma Members:

J. E. Baker
W. Burt
B. J. Cassidy
B. H. Cross
R. L. Gardner
R. A. Hall
G. W. Lawlor
M. A. Moloney
B. J. O'Dwyer
M. A. Ryle
J. J. Toomey
M. J. Wells

New Members

The following applicants have been duly elected by the Council to Membership of the Society:

Corporate Members

Asa'd, A. A.	P.O. Box No. 1568, Kuwait.
Chivers, D. R.	12 Oakbury Road, London, S.W.6.
Chorlton, J. M.	59 Spadina Road, Toronto 4, Ontario, Canada.
Clarkson, B. N.	Crompton Parkinson Ltd., Crompton House, Longley Lane, Wythenshawe, Manchester 22.
Cuttle, C.	Ash Lodge, Pump Hill, Loughton, Essex.
Evans, B.	5 Teignmouth Road, Welling, Kent.
Fussell, F. G.	20 Winfield Road, Warmley, Bristol.
Gredley, H. J.	10 Guy Road, Wallington, Surrey.
Haythornthwaite, R.	23 Cookridge Avenue, Cookridge, Leeds, 16.
Holmes, A. D.	112 Hawthorne Road, Castle Bromwich, Warwickshire.
Kovacs, A. I.	Flat 31, Eton College Road, London, N.W.3.
McKay, A.	74 Northumberland Street, Edinburgh, 3.
McKenzie, R. A.	63 Royal Hill, Greenwich, London, S.E.10.
Morgan, W.	69 Newlands Avenue, Melton Park Estate, Gosforth, Northumberland.
Price, F. W.	70 Selwyn Crescent, Welling, Kent.
Sanderson, D. S.	2 New Barn Close, Shaw, Oldham.
Sayeed, M. M.	42 Campden House, Harben Road, London, N.W.6.
Smith, A. H.	90 Ruskin Road, Carshalton, Surrey.
Stephenson, W.	15 Long Lane, Worrall, Oughtibridge, near Sheffield.
Walton, S. K.	First Floor Flat, All Saints House, Pilgrim Street, Newcastle-upon-Tyne.

Transfer from Student to Corporate Membership

Cutts, B.	'Delamere', 59 Wickersley Road, Rotherham.
Taylor, B.	48 Eastbrook Road, Waltham Abbey, Essex.

Students

Dumville, A.	4 Crawshay Rise, Pudsey, Yorkshire.
Howes, B. J.	54 Western Road, Wylde Green, Sutton Coldfield, Warwickshire.
Rapley, J. F.	37 Mayfair Avenue, Bexleyheath, Kent.
Share, A. J.	40 Gorse Farm Road, Great Barr, Birmingham, 22a.

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